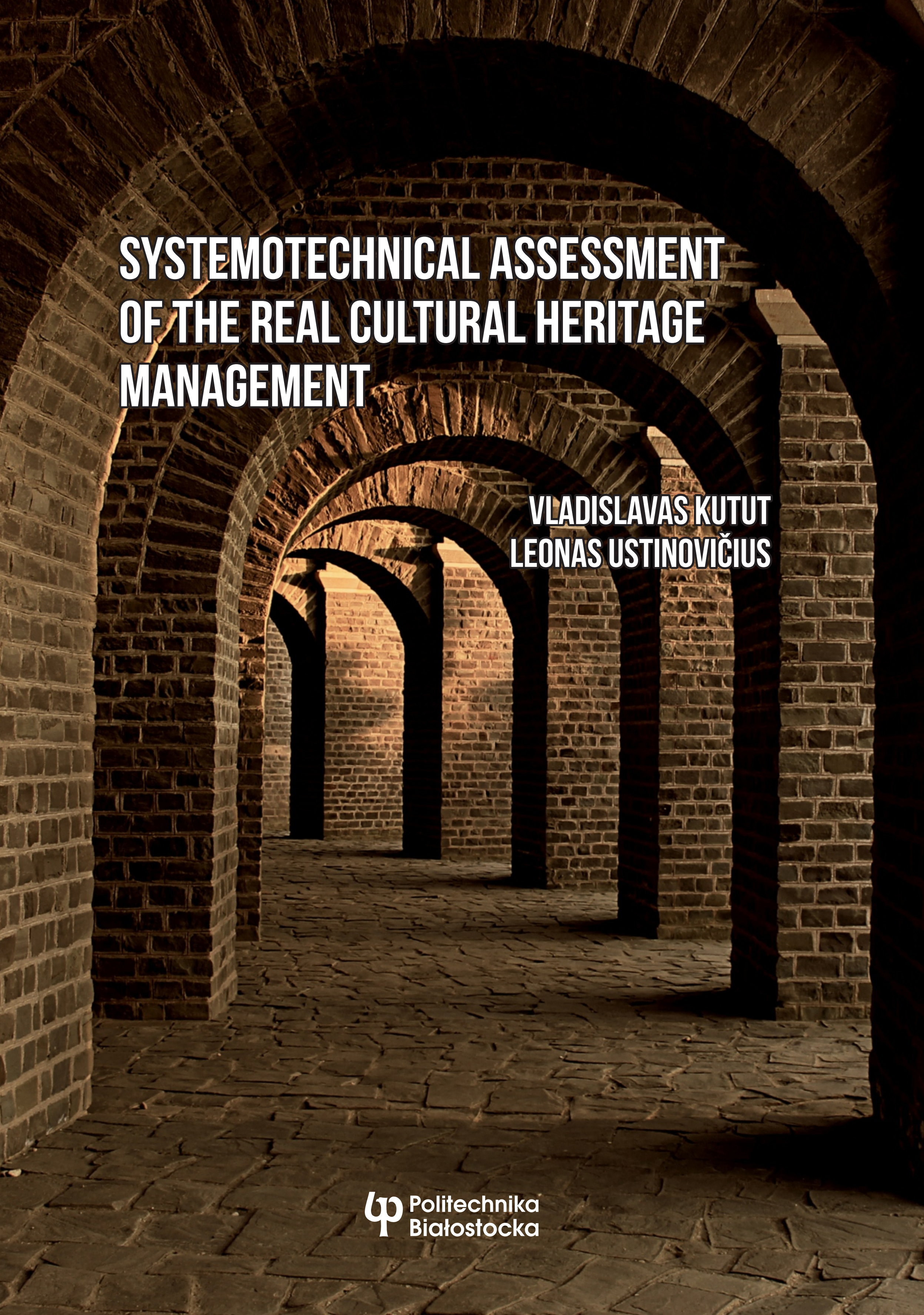

SYSTEMOTECHNICAL ASSESSMENT OF THE REAL CULTURAL HERITAGE MANAGEMENT

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Spis treści

Preface

Identification of the immovable cultural property management options is analyzed in this book by applying mathematical modeling and selective – innovation of multipurpose methods, which allow us to make comprehensive assessments of infrastructural, technological, technical, heritage, social, economic, legal aspects of the immovable cultural property management.

The main goal is to create a theory and a decision-making support system based on it, to increase the efficiency of investments in the immovable cultural property management by applying the mathematical modeling and selective – innovation of multi-purpose methods.

The authors describe the multi-criteria decision-making support systems for the immovable cultural property management projects and the ways of their practical application. Several practical decision-making solutions are presented, and a decision-making support system is developed to implement the described methods and techniques.

The publication is devoted to the researchers, engineering technologists, cultural heritage protection specialists, managers, Ph.D., and Master's degree students that are interested in the immovable cultural property research, design, and restoration management.

Introduction

Cultural heritage is a living witness of our past, preserving traces of well-known or long-forgotten events. Immovable cultural heritage is a valuable relic and document of the past, a witness to historic development that will have great cultural significance for society in the future as well. Therefore, preservation and transmission of the cultural heritage to future generations is relevant. The implementation of this goal is a cumbersome and responsible process. Consequently, the proper use of the cultural heritage objects for the social needs, linking them with the economic, social, and cultural development, is a task of high importance to connect them with a state economic, social and cultural development. First of all, it is necessary to assess cultural heritage objects.

It is necessary to take into account the particularities and the value of cultural heritage protected properties when analyzing the tendencies of real estate development in cultural heritage territories. The value of properties is determined by analyzing the historical – archaeological, historical – architectural, architectural, compositional and technical, and economic value of the properties, which affects the real estate development prospects.

Taking into account that cultural heritage and its preservation is one of the mainstreams of the European Union, the real estate development in cultural heritage territories acquires significance and importance as for many factors must be taken into account, i. e. it is necessary to note preference in the concept of the urban area while setting the main criteria for preservation and development, to improve the attractiveness of investments in cultural heritage territories it is necessary to follow the legal basis for cultural heritage protection and continuously improve forms and methods.

Real estate development in cultural heritage territories is not possible without engaging society. Foremost, the indigenous peoples, by preserving and integrating the cultural heritage objects into the social and economic life of the city or territory, by inducing tourism, the return on investment, by maintaining or restoring the monuments. The use of the brand name of monuments is significantly affecting the value of the real estate in historical districts and cities and ensuring the return of funds invested in restorations.

Cultural heritage is a system of components that is difficult to measure and evaluate, influenced by economic factors. Over the decades, many researchers have endeavored to apply a variety of economic theories and methodologies to their researches of cultural heritage.

Several "Cultural Economy" guidelines have been developed to explain the value of cultural heritage and cultural capital, and some aspects of the environmental theory are applied to the assessment of cultural heritage as well. Nevertheless, determining the physical and economic value of cultural heritage is a complex and highly subjective task as it relies on the application of engineering methods.

The UNESCO Guidelines for the Implementation of the World Heritage Convention clearly define cultural heritage as a set of various physical forms created by a human, with exceptional global aesthetic, historical, ethnological, or anthropological value. The axis of the UNESCO concept of cultural heritage is an exceptional universal value, whether substantial or intangible, which is a crucial indicator when comparing values at the global level and setting guidelines for the preservation and management of cultural heritage.

The specific characteristics of the cultural heritage object management play an essential role in protecting the heritage objects. Privatization of cultural heritage is important but, at the same time, a highly controversial topic.

Due to the important global value of the significance of heritage objects, they are more often managed by the State than by individuals. In the case of privatization, public-interest is pursued through private efforts, but profit – is the goal of the private sector that does not correspond with the public interest.

However, when certain rights and responsibilities are unified and expressed in quantitative or qualitative terms, the management of heritage objects becomes more of a communal and dependent on community regulatory mechanisms. Privatization substitutes the direct intervention of the State. Still, private interest groups could have influenced the heritage objects management even before privatization, the interference of whom maybe even less noticeable while the State has the disposal over the objects.

The dynamism of the modern world and rapid changes in the society pose a serious threat to the preservation of cultural heritage buildings which therefore should be adapted to the changes and needs of modern society.

The re-use of cultural heritage buildings is accepted as the conversion of a cultural heritage object into use thus reconciling the needs of the manager and the public minimally changing valuable properties and enabling the building to be restored to its pre-existing condition. The adaptation of the introduced buildings becomes important when it comes to preserving and maintaining the value of a morally and physically obsolete building. In addition, the proper reuse of cultural heritage buildings promotes the sustainable preservation of heritage buildings and the environment.

The re-use of heritage buildings allows the structures to be preserved thus providing constructions with new functions and performance and reviving the heritage building to the 'second life'.

The term of adapting a cultural heritage building (re-use of the building) is defined as the conversion of a cultural heritage object and its components into use thus reconciling the needs of the manager and the public minimizing valuable properties, enabling the pre-existing condition and conducting research-based applied heritage conservation, construction and landscaping works.

The adaptation of the cultural heritage building becomes significant when it comes to preserving and morally and physically maintaining the value of an obsolete building. Moreover, the adaptation of the cultural heritage building changes only the function of using the building, which is adjusted to the needs of the modern community.

The proper re-use of heritage buildings promotes the sustainable preservation of heritage buildings and the environment. The adaptation of the building must be based on economic and social needs that ensure the uniqueness of the building itself and the historic environment and contribute to the preservation of cultural heritage. So, five elements, including economic, environmental, technological, legal and physical, affecting the reuse of buildings can be distinguished.

Cultural heritage adaptation is intended for cultural and culture-related educational, economic, social and similar needs. Adaptation is aimed at preserving and disclosing valuable features of heritage sites, creating preconditions for increasing visitors' flows, performing new and developing available activities, involving local creative communities, generating public interest in cultural heritage and improving the national image as a tourist attraction to domestic and foreign markets.

Nevertheless, only a small part of cultural heritage has been preserved and restored leaving their ruins or adapting the survived preserved buildings for museum activities.

The rest of cultural heritage requires research and other building adaptation goals are focused on the re-use of heritage. Given historic buildings are capable of gradually adapting to permanent changes, the initial intended use of the buildings is hardly necessary, although it is always a priority.

Thus, the correct material and spiritual use of historic buildings is possible meeting the needs and goals of modern society.

The concept of restoring the building is accepted as the restoration of a dilapidated heritage object of exceptional cultural value and extraordinary full-scale significance.

The possibility of recovery must be based on detailed data obtained from historical sources and physical research. Restoration preserves and renovates surviving parts and items thus sending them back to the original location, while non-surviving parts and items are accurately replicated and restored. Restoring the building or a set of buildings usually means carrying out maintenance activitiesthat cannot be defined as the restoration of cultural property.

This type of maintenance works aims to select the importance of modifying the building and restore the uniqueness and artistic significance of the construction.

However, considering the current situation and the needs of modern society, it could be proposed that a focus of restoring cultural heritage objects must be shifted on the initiatives, needs and solutions of heritage users-community and citizens involved in the restoration process itself rather than on the historicity and authenticity of buildings.

In order to properly preserve the valuable properties of the cultural heritage building, maintenance works must be carried out on the basis of detailed research into the heritage building and a thoroughly prepared maintenance projectof heritage and construction employing specific materials and technologies that ensure the uniform treatment of the already available building materials over time.

In addition, the proper performance of the above introduced works must be ensured by the acquired knowledge, developed skills and gained experience in a certain field (architects, engineers, contractors, art critics, historians, etc.).

Effective planning and management of investment activities are becoming not only a significant but also a complex process when it comes to investing in old towns and heritage areas.

Investment calculations become an expensive corporate management tool when planning investments. They are interpreted as the alignment and evaluation of investment decision-making models. Therefore, investment calculations use not only methods and models based on revenue and expenditure researches but also multi-purpose decision methods assessing the utility.

Such an approach to investment calculations is purposive because investments often have an impact that cannot be measured in monetary values.

To determine the efficiency of a building restoration investment, it is necessary to make a complex analysis of the stages of its establishment, taking into account the findings of the research and the level of preservation of the heritage object. Investment options are then examined based on multi-criteria methods.

According to the selected option, a restoration project of the building located in the heritage protection area with a productive architectural, structural, and monument protection solution is being prepared.

The stage of determining funding methods is crucial because the ultimate success of investment often depends on it. All investors solve the problem of determining the reliability of the chosen option.

It is necessary to apply a particular mathematical model at each stage. These can be methods based on quantitative measurements, methods based on initial qualitative measures; comparative preference methods, verbal analysis decision – making methods.

1. Real estate development in the territory of cultural heritage

1.1. The life cycle of a historic building

The reconstruction of historic buildings is affected by strong economic motives. The benefits of renovated heritage objects are observed not only for individual entities but also for more extensive territories and communities. The inclusion of cultural heritage objects in global regeneration schemes is becoming an essential catalyst for sustainable development. Successful regeneration of heritage objects has a far-reaching effect that goes beyond the site and has a positive impact on society and the city (Kutut, 1994).

In theory, the regeneration of a cultural heritage object is necessary to avoid a downturn of the physical, economic, and social characteristics of the object. It is also important to note that the renovation of a cultural heritage object in urban areas must integrate into the urban environment and its development. What is a successfully developed urban environment? What do many people see as components of a successful urban environment? The main elements are:

- streets, not roads
- variety of opportunities offered by the urban environment
- variety of building styles
- reduction/absence of traffic
- public spaces
- well-maintained buildings and pavements
- public occasions for the community to influence urban space
- attractive design solutions for specific spaces
- ensuring security
- maintaining authenticity as a counterpoint to the artificiality

Significant as the overall impression and atmosphere in a particular urban space. However, different buildings can become an important reference point to create an atmosphere of a thriving environment. Heritage objects often help to regenerate the surrounding environment by incorporating their historical and economic value into the surrounding overall. Reconstruction of historic buildings can create an environment where people want to work, live, or visit. Successfully developed historical places, districts, or blocks become the desire of people to be in these historical-cultural environments (Lehtimäki, 2009).

People are rushing to such areas because here they are given:

- different spaces, types, and sizes of the buildings and variety of uses
- interesting architectural details
- beauty of architecture
- local specificity
- associations with the past
- richness and warmth of design
- the physical form of the transformation
- positive social atmosphere
- the historical meaning of the place
- quality of life

1.2. Objects of cultural heritage in terms of sustainable development

Renovation and revitalization of cultural heritage objects is an essential axis for sustainable development. Cultural heritage can be used to strengthen the local economy, attract investments, highlight local distinctiveness, and the added value of the real estate in a particular environment.

The reconstruction of cultural heritage objects may be more expensive than initially estimated by the owners. However, frequent research suggests that the increased estimates during the work process may be lower than the construction of new objects that do not create as much economic value as the historic buildings. Energy resources, the abundance of materials used, and the waste generated in the construction of new buildings provide fewer advantages than the resurrection of an object to life in terms of sustainable development. Cultural heritage buildings and areas are rich in materials suitable for reuse. The reuse and savings of energy and materials are a critical aspect of these times of energy crisis.

The reconstruction of historic buildings also reduces the amount of gas generated during construction, loading the landfills, and household waste emissions, which directly affects the greenhouse effect indicators (Figure 1.1) (Kaklauskas *et al.*, 2012).

Reinvestment in historic sites ensures the preservation of inherited buildings, spaces and places for future generations. At the same time, the reconstruction of protected objects allows to incorporate new historical layers, reflecting specific talents, aspirations, and eras in the newly restored object. This way, different historical eras interlock in one object. The preservation, renovation, and reconstruction of historic buildings reflect the success of sustainable development.

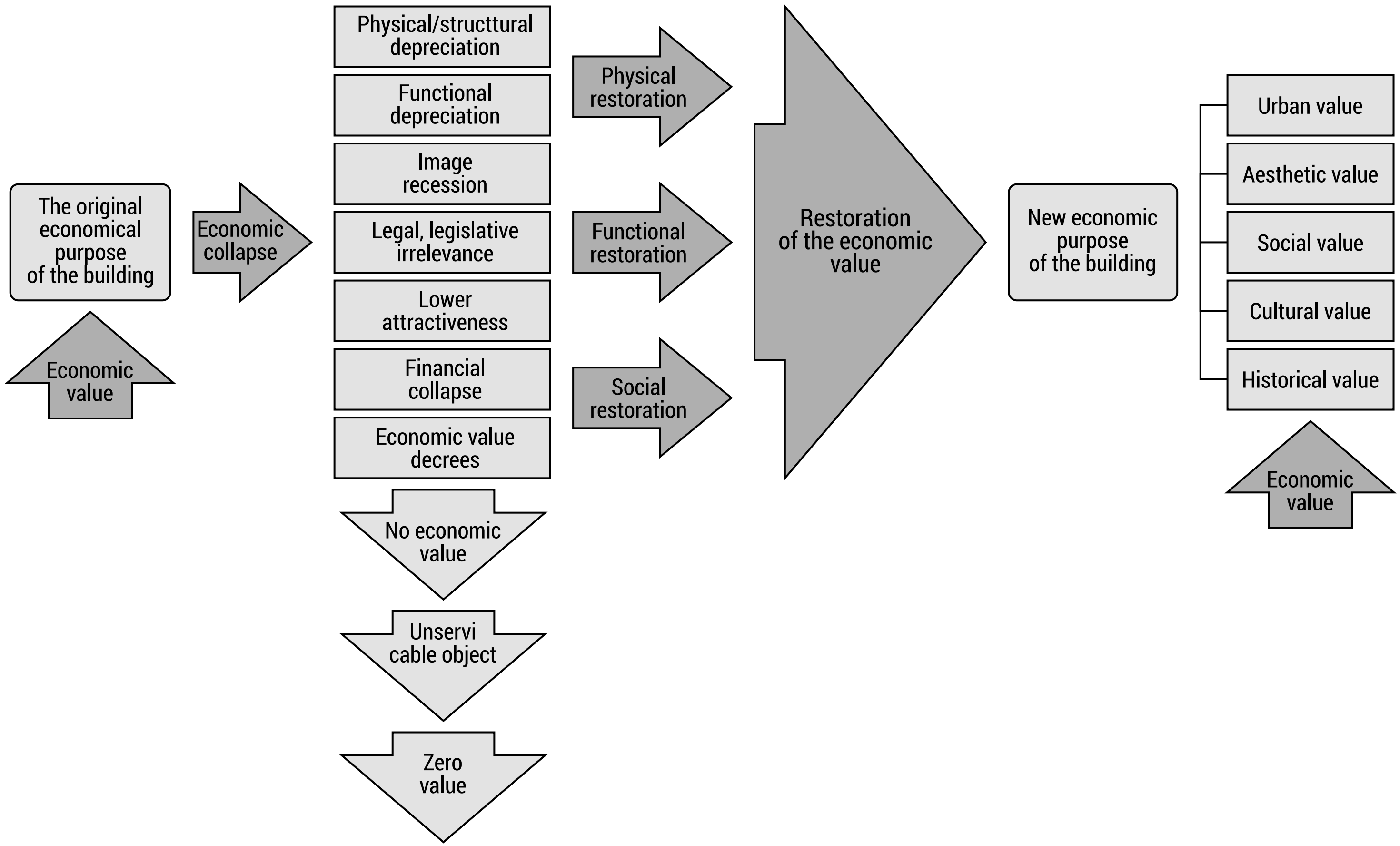


FIGURE 1.1. The life cycle of a historic building

In the conclusion of the analysis of the life cycle of the historic building, it is clear that the historical, urban, and cultural value of the heritage building plays a decisive role in the new economic purpose of the heritage building.

1.3. Measures and targets of heritage management in the context of immovable cultural heritage development

Aspiration	Measure
To coordinate the goals of protection and use of cultural heritage values	• to seek for development and protection measures, to reconcile public and private interests; • to expand old and more widely apply new technologies and materials for the revival, restoration, and renovation of cultural heritage.
To prepare favorable conditions for tourism development	• to evaluate cultural heritage as a material and visual commodity; • to identify cultural heritage objects according to the incorporation for inspection, services, infrastructure, taking into account the cultural value and social significance of the heritage.
To develop an effective compensation mechanism for cultural heritage preservation	• to develop measures for the effective application of grants, subsidies, loans, technical means, and tax breaks, and increase the efficiency of services.
To integrate heritage protection into the State's economic, social and cultural development strategy	• to create a legal, financial and managerial framework that meets the needs of integrated heritage protection; • to bridge the gap between state and public heritage initiatives.
To improve heritage protection and heritage management methods and technical measures	• to change the environmental provision of *heritage protection by prohibiting* to *protection and management principles* for cultural heritage protection; • to search for new ways of protection and reconstruction of cultural heritage values, restoration means, technologies and materials; • to share the experience with foreign heritage protection and heritage management professionals, interested institutions, community masters; • to apply local skills, traditional handicraft methods, materials, regional architectural traditions in new construction.
To solidify Lithuania's image in Europe and the world by using cultural heritage	• to publicize cultural heritage in Lithuania, Europe, and the world by all means of teaching, promotion and visual cognition; • to foster building traditions and expand the sphere of cultural heritage resources and historical plots relevant to the region; • to extend all forms of recreation and international cultural tourism.

1.4. The impact of the immovable cultural heritage on real estate development

Cultural heritage is divided into immovable and movable cultural heritage. This section addresses the immovable cultural heritage. Cultural heritage is a system of components that are difficult

Over the last decades, many scientists endeavor to adapt to a variety of economic theories and methodologies to study cultural heritage. Several "Cultural Economy" guidelines have been developed to explain the value of cultural heritage and cultural capital value, and some aspects of the environmental theory are applied to the cultural heritage assessment. Nevertheless, determining the physical and economic value of cultural heritage is a complex and highly subjective task as it relies on the application of engineering methods.

The UNESCO Guidelines for the Implementation of the World Heritage Convention clearly define cultural heritage as a set of various physical forms created by a human, with exceptional global aesthetic, historical, ethnological, or anthropological value. The axis of the UNESCO concept of cultural heritage is an exceptional universal value, whether substantial or intangible, which is a key indicator when comparing values at the global level and setting guidelines for the preservation and management of cultural heritage (Glemža, 2002).

Let's take an example of a classic cycle of community cultural tourism development, influencing the growth of real estate and cultural identity:

- **Stage 1.** The place is becoming known as a cultural heritage site and is starting to attract visitors. Local communities are starting to renovate their homes to attract tourists. So far, revenue comes only from internal visitors.
- **Stage 2.** The value of land and buildings is increasing; infrastructure development is beginning, non-local community (external) buyers are looking to buy land and rental houses around the monument to develop the tourism business on a larger scale. Residents receive income again, but this time from remote or external (non-local community) individuals.
- **Stage 3.** Abrupt hotel construction begins, environmental conditions deteriorate, locals become mercenaries for the outside communities, and then the increasing members of the local community leave the area and move out, selling their land and other real estates.
- **Stage 4.** Many businesses developed in particular areas are owned by non – local community members, so money "float" from different sources. Investment projects are growing in the area; processes are accelerating and are taking place regardless of local legal or political regulations. Residents are becoming a weak and vulnerable group and start to express anger over tourists. Cultural and social structures of local communities are being dismantled, and representatives of special interest groups are not allowing this vicious circle to be stopped.

- **Stage 5.** The environment is being destroyed, the area is being overcrowded, overdevelopment and over-commercialization are reducing tourist flows, residents would like to live in pristine conditions and take remedial action, but all control is made by entrepreneurs who regulate environmental conditions and are free to withdraw or relocate. The local culture adapts to the needs of tourists, distorts, and loses its original originality.

1.5. Management features of objects of cultural heritage

Privatization. Privatization of cultural heritage is necessary and, at the same time, a highly controversial topic. Due to the important value of the universal significance of heritage objects, they are more often managed by the State than by private individuals. In the case of privatization, the public interest is pursued through private efforts, but the goal of the private sector is profit-making and never coincides with the public need. However, when certain rights and responsibilities are unified and expressed in quantitative or qualitative terms, the management of heritage objects becomes more community – based and becomes dependent on community regulatory mechanisms. Privatization substitutes direct state intervention, but even before privatization, the supervision of a heritage object could have been influenced by groups of private interest, whose intervention when the object is at the possession of the State maybe even less noticeable.

Privatization means a reduction of public funding to support an object. This can commence the instability in financial flows when private capital for the disposal and management of a heritage object is attracted from cyclical and volatile economic activities such as tourism, real estate operations, etc. Therefore, the privatization of heritage objects for tourism and authentication purposes can sometimes be inappropriate.

Cultural heritage objects preservation requires constant processes of restoration and conservation of specialized skills and work are necessary that the owner is often not able to perform. Voluntary based and arbitrary renovation works supported by the economic impulses of the owner can destroy the authenticity and integrity of the object, damage, and reduce the value. When the damage is irreversible, the private owners lose the economic interests as activities may become impossible or restricted. (Drėmaitė *et al.*, 2007)

However, in many cases, successful privatization is the basis for successful tourism projects.

The most common way of cultural heritage management is through State ownership. This form of management also involves complex regulatory mechanisms that complicate the management process – i.e., the constant control of the state institutions involved, the changes in legislations the interventions of regional and local authorities, the interests of stakeholders and related communities – all this can make the disposal of an object a problematic task. However, in most countries, the State is the primary owner of the cultural heritage, or at least the authorized owner of the property, so state regulation of the heritage is reasonable.

The idea of the coherence and sustainability of cultural heritage is a primary distinguishing feature that separates the goals of state management from private ones. As we know, sustainable development means development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Typically, the State operates the following measures regarding cultural heritage:

1. the object is fully owned and managed by the State institutions or public social organizations;
2. granting the state support, as well as subsidies or indirect funding, or create opportunities to tax or other financial benefits for the conservation, restoration or maintenance of a privately – owned objects;
3. the state restrictions for the privately-owned objects' management or regulations of possible or mandatory actions;
4. education and the provision of comprehensive information to private hosts to preserve the universal value of cultural heritage and to prevent the destruction of the value.

1.6. Heritage protection policy and regulatory

The best-known international organization in the field of cultural heritage is UNESCO (The United Nations Educational, Scientific, and Cultural Organization). The intergovernmental organization ICCROM (The International Centre for the Study of the Preservation and Restoration of Cultural Property) is operating as well and is dedicated to the preservation of cultural heritage, provides training for specialists. International non-governmental organizations are operating as well in this field, such as ICOMOS (International Council on Monuments and Sites), whose work is aimed at specialists in the protection of historical monuments and sites (UNESCO Expert Advisory Organization).

The UNESCO World Heritage Management System has few controversial challenges. The Convention accepted by the UNESCO in 972, defines the management of cultural heritage at international level by introducing the concept of World Cultural Heritage, setting guidelines for the work of the World Cultural Heritage Committee to be responsible for implementing the Convention and distributing the World Heritage Fund, and compiling the World Heritage List. The World Heritage List includes 890 cultural and natural heritage objects that are defined as having outstanding universal value by the World Heritage Committee. However, the main feature is the imbalance in World Heritage objects' allocation around the world (Figure 1.2).

FIGURE 1.2. Geographical origin of the world heritage objects (source UNESCO)

The figure shows that world heritage objects geographically are dominant in the Western Europe part. The criteria for valuing European cultural heritage sites are controversial because, according to Yukio Nishimura (1995), "The concept of authenticity cannot be as static as in Europe, because the basic perception of cultural properties in Asia is different from that in Europe". The result is an unusually high number of global cultural assets in Western Europe and their scarcity in Eastern Europe or third world countries. Thus, the third world countries have no exposure to the UNESCO organization and feel "outside" treating the organization as a regulatory body rather than a cooperating body.

Another characteristic that causes an unequal allocation of World Heritage objects is UNESCO's requirement to maintain the value of cultural heritage objects always, i.e., properly preserving, maintaining, and restoring them. Developed countries can perform this task due to sufficient funding. The underfunding of cultural objects in the least developed countries (LDC) or countries with severe economic conditions prevent the inclusion of the heritage objects in the World Heritage list, which has a direct impact on the growth of cultural tourism flows.

The last characteristic to be mentioned is the inequality of methods for preserving the value of cultural heritage. International regulation of cultural heritage conservation aims to preserve the cultural diversity and value of local communities. Still, it allows them to conserve and preserve that value in many ways and means, often distorting the result.

Cultural heritage is a historic achievement for each country and its residence. The diversity and distinctiveness of the heritage tell about the country's historical past.

Material cultural heritage is material objects and relating places from the past with historical, archaeological, ethnological, mythological, memorial, religious, architectural, urban, artistic, and scientific values.

The heritage of material culture is conditionally divided into movable and immovable.

Movable cultural heritage consists of the most valuable material works and objects created by humans and society, with the cultural value of significant ethnic, archaeological, historical, artistic, scientific, technical, religious, and other respects.

The immovable cultural heritage consists of objects, their groups, ensembles, and objects associated places with archaeological, ethnological, mythological, memorial, religious, architectural, technical and technological, urban, historical, artistic, and scientific values. Movable historical or artistic values contained in cultural heritage objects – buildings – are considered to accessories and are assigned as immovable cultural values. The immovable cultural heritage may classify:

1. buildings – castles, palaces, town halls, churches, monasteries, schools, residential houses, estates, parks, etc.;
2. urban heritage objects – historical parts of the city, old towns, their quarters, townships;
3. places of historical events, buildings, and related objects, objects that are associated with famous state figures, writers, artists, scientists, their lives, history of science and technology;
4. visual monumentalism, applied and decorative art, and their fragments.

The UNESCO cultural heritage objects since the year 1972:

- **monuments** – architectural buildings, monumental sculptures, and paintings, as well as cave dwellings and inscriptions, structures, elements and their groups of archaeological, historical, artistic or scientific values;
- **ensembles** – groups of individual or connected buildings that have a unique historical, artistic or scientific value due to their architectural integrity or connections with the local landscape;
- famous places – topographical areas, mutual works of human and nature of exceptional value due to their beauty or their archaeological, historical, ethnological, or anthropological importance.

The European cultural heritage conventions on the archeology (accepted in 1992) and architecture (approved in 1985) contain the following definitions:

- **archaeological heritage is** – a source of historical and scientific research for Europe's collective remembrance. All remains and objects and other traces of humanity from past epochs must be considered as an archaeological heritage:
    1. the preservation and research of which would help to reveal the connection of human history with the natural environment;
    2. the primary source of information of which is excavations find, or other results of the study of humanity and its environment, both on earth and underwater.
- **architectural heritage is:**
    1. monuments: all structures of historical, archaeological, artistic, scientific, social or technical performance, together with interior decoration and accessories;

2. groups of buildings: homogeneous groups of urban or rural buildings forming common compounds, important from the historical, archaeological, artistic, scientific, social or performance technical point of view; those groups of structures also form topographically defined units;
3. areas: standard creations of human and nature, partly built-up, sufficiently prominent and connected as a whole, topographically defined and of historical, archaeological, artistic, scientific, social or technical significance.

1.7. Management and reconstruction issues of cultural heritage buildings

1.7.1. Cultural heritage research literature analysis

Cultural heritage is the basis of spiritual, cultural, artistic, architectural, economic, social, technical, and technological values, which is extremely important for the development of each person's identity and public behavior (Turnpenny, 2004). Although cultural heritage was previously associated with artistic and architectural works now it is defined as an environmental element, an industrial or folk dwelling-type building, urban and rural settlements, and intangible elements related to community activities and lifestyles (Chung, Lee, 2019).

The existing research determined cultural heritage values must be retained during the preservation, restoration, reconstruction, or re-adaptation process. In that context, heritage protection management and construction works must be carried out following the regulations of the heritage management, the Law of the Immovable Cultural Heritage Protection, construction technical regulations, the Construction Law, and others. There are two ways for the cultural heritage buildings to be preserved: a) physical characteristics, where cultural heritage buildings are complex, unusually shaped or heterogeneous, the building shell is not insulated, passive and natural ventilation are used, and the buildings are built according to national construction methods and natural non-standard materials are used; (b) principles of preservation, where heritage management and construction works of cultural heritage are carried out under the established protection rules and good practices for the protection of the historical value of a building and other established values (Webb, 2017).

Researchers use a variety of multiple decision-making methods (MCDM) to preserve, restore, reconstruct, or re-adapt cultural heritage buildings. MCDM methods can be divided into two categories: discrete MCDM or discrete Multiple Attribute Decision Making (MADM) methods and Multi(ple) Objective Decision Making (MODM) methods (Zavadskas *et al.*, 2014).

The Clarivate Analytics database published more than 1039 articles in English between 1980 and 2018 (until November 11th, 2018) defining terms of "heritage building" and "historical building". Only 17% of which used multicriteria analysis, multicriteria decision-making, indeterminate sets, and other methods to solve problems of cultural heritage buildings (Figure 1.3).

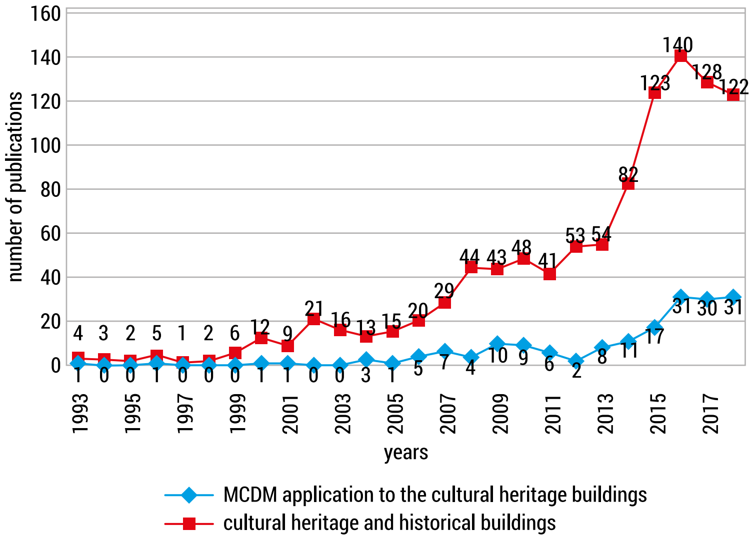


FIGURE. 1.3. Comparing the topics of cultural heritage buildings with MCDM methods application in cultural heritage buildings area according to the number of papers published from 1993 to 2017 (Morkūnaitė *et al.*, 2019)

1.7.2. The overview of factors that determine the performance of the management and reconstruction of cultural heritage buildings

Preserving cultural heritage buildings for future generations is one of the main goals around the world. Specialists, scientists, restorers, and government officials in various fields extensively study and analyze the factors that determine the performance of cultural heritage building management works.

Researchers often examine several cultural heritages interrelated or interacting areas. These main groups of areas at issue are distinguished into building materials and building structures (Zampieri *et al.*, 2018), Heritage Building Information Modeling (HBIM) and building materials (Argenziano *et al.*, 2018), earthquakes and building structures (Shakya *et al.*, 2018; Gaetani *et al.*, 2017; D'Altri *et al.*, 2017; Ruiz *et al.*, 2017; Castori *et al.*, 2017; Petrovcic, Kilar 2017; Formisano, Marzo 2017; Clementi *et al.*, 2016; Limoge-Schraen *et al.*, 2016; Cakir *et al.*, 2016; Garofano, Lestuzzi

2016; Aras, Altay, 2015; Ferreira *et al.*, 2015), re-adaptation and earthquakes (Abeling *et al.*, 2018), sustainability and re-adaptation (Al – Obaidi *et al.*, 2017; Castaldo *et al.*, 2017; Blagojevic, Tufegdzin, 2016), etc.

The UNESCO World Heritage "World Heritage Sites" list of 2018 refers to1092 heritage objects around the world, 77% of which accounts for the cultural heritage. The list also indicates that Italy has the highest number of cultural heritage sites (49 sites), followed by Spain and Germany, where each has 41 cultural sites, 39 – in France, 36 – in China, 29 – in India, and Mexico – 27. However, these countries also fall into potential seismic hazard zones. Scientists in Italy, Portugal, Spain, and New Zealand have focused on earthquakes and their impact on cultural heritage buildings.

Bartoli *et al.* (2017) identified seismic hazards for masonry towers of historic buildings following the Italian "Guidelines for the Assessment and Reduction of Seismic Hazards in Cultural Heritage". Peruzzi *et al.* (2017) assessed the seismic hazard of the city of San Gimignano in central Italy as part of the "Seismic Hazard of Cultural Buildings" project. Local seismic response analysis was validated and the most critical areas of the buildings were identified because of this project. Therefore, according to the author, to reduce the seismic risk of these areas, their strengthening must be ensured. It is also worth mentioning that this Italian city is a UNESCO World Heritage Site due to its unique architecture – the predominant historic towers.

Climate and its change determine the "depreciation" of heritage buildings. In this regard, the effects of air temperature and humidity on historic building structures (Parkin *et al.*, 2015) and climate-sensitive projects were considered, taking into account quantitative and qualitative indicators, including the interface with historic building forms and structures, materials, construction technology, location, and climate (Rubio-Bellido *et al.*, 2018).

As already mentioned, historical, artistic knowledge, technical abilities, and competencies are required for the management or reconstruction of the heritage buildings. Besides, the construction of the building, the materials used, the technology should be evaluated and a detailed historical-artistic study of the restored building should be carried out. In this context, many scholars have discussed a variety of emerged or emerging issues related to the construction of heritage buildings, such as restoration of masonry arches using reinforcing springs (Zampieri *et al.*, 2018), wooden panel floors and roofs (Faggiano *et al.*, 2018); masonry and/or wooden structures (De Ponti *et al.*, 2017; Panto *et al.*, 2017; Ademovic, Kurtovic 2017; Qiao *et al.*, 2016; Cruz *et al.*, 2015; Gubana, 2015; Sassoni *et al.*, 2014; Barluenga *et al.*, 2014), unreinforced clay brick masonry (Lumantarna *et al.*, 2014), masonry domes (Lanca *et al.*, 2015), masonry groined domes (Gaetani *et al.*, 2016; Vidal 2017), and their possible behavior during an earthquake (Gaetani *et al.*, 2017; D'Altri *et al.*, 2017), arcades (Diaferio *et al.*, 2018; Ramaglia *et al.*, 2016), stone masonry (Lucchi, 2017; McGibbon, Abdel – Wahan, 2016), and concrete structures (Marcos *et al.*, 2018). Meanwhile, Witzany *et al.* (2017) examined the results of laboratory researches on the physical and mechanical properties of masonry structures in heritage buildings. Demir and Ilker (2014) investigated the mechanical behavior of multilayer masonry walls in heritage buildings. The study included a series of mechanical, metallurgical, chemical tests. These tests were performed with lime mortar, crushed stone masonry, and iron materials. Oliveira *et al.* (2012) analyzed the behavior of a three-layer masonry wall during compression. Also, a general method of masonry wall reinforcement has been improved, which made it possible for the compressive strength of walls to increase. Sekularc *et al.*, 2017 evaluated the deformations of the structural components of a heritage building. It is known that the restoration of the used materials is important when the restorer must choose new modern materials and match them with the remained used materials. To properly select these materials, researchers have previously discussed existing building materials, their characteristics such as Godene travertine (stone) (Gokce *et al.*, 2016), sandstone (McSkimming, 2015), lime mortar (Klemm, Wiggins, 2015; Borges *et al.*, 2014), the composition of restored light natural limestone (Sala *et al.*, 2016), the surface roughness of stones used for heritage buildings (Korkanc, Savran, 2015) and the possible impact of climate (Jin *et al.*, 2017) of wind and rain (Erkal *et al.*, 2012) on the brick surface. Moreover, Micellietal (2014) examined fibrous reinforced polymers. The masonry of buildings is reinforced due to these polymers, thus mitigating its vulnerability. Morillas *et al.* (2018) introduced new modern building materials used in the preservation and restoration of heritage buildings. A suitable selection was suggested, taking into account different factors, e.g. marine aerosol, water penetration, physical stress, pollutants, etc. Damas *et al.* (2018) investigated the detailed properties of glazed tiles, otherwise known as "azulejo", with a focus on their suitability for building conservation and restoration work. Govaerts *et al.* (2018) evaluated the limestone finishing insulation of heritage buildings and compared its hydrothermal behavior with the traditional building insulation solution. Meanwhile, Perez-Monserrat *et al.* (2018) proposed a preventive model for building maintenance, focusing on building materials and their "sensitivity," e.g. limestone can be aesthetically damaged by cracking at their edges. This model would reduce the number of maintenance work and building management costs.

Another important factor determining the reconstruction of cultural heritage is energy consumption reduction and modernization. The challenge of energy efficiency and modernization of existing buildings has become one of the strategic goals of the European Union for the coming years. Cultural heritage buildings, that require energy efficiency insurance, are no exception. However, the preservation and restoration of these buildings are subject to strict and specific requirements and rules, and the application of energy efficiency measures must be compatible with these requirements. Besides, energy efficiency measures can change the aesthetic and architectural values of a heritage building. Therefore, in most cases, the use of renewable energy and energy efficiency measures is not allowed, unless they are hidden and/or do not violate the aesthetic, architectural, cultural value. Nevertheless, researchers are intensively exploring the possibility of ensuring energy efficiency and retrofitting in heritage buildings.

The energy modernization related researches are presented by Blecich *et al.* (2016), Tadeu *et al.* (2015), Filippi (2015), Mazzarella (2015). Studies such as Sahin *et al.* (2015), who proposed interdisciplinary energy modernization of heritage buildings, De Santoli (2015) guidelines for increasing energy efficiency measures, Moran *et al.* (2014) energy conservation proposals based on passive house planning principles could be discussed extensively too. Perez-Garcia *et al.* (2018) proposed the energy conservation potential of heritage buildings, taking into account the structural properties of the building, i. y. the „skeleton" of a building, consisting of the external walls of the building, windows and doors openings, the floors and the roof. The proposed modern measures to improve the thermal characteristics of heritage buildings. Litti *et al.* (2018) presented the life-cycle energy-saving potential of a building concerning the restoration or windows replacement. Franco (2018) proposed the use of solar energy technologies for energy production in heritage buildings. The result of this study is to determine the compatibility of landscape and architectural indicators, taking into account the characteristics of the heritage building. Okutan *et al.* (2018) introduced a three-step process that allows increasing the energy efficiency of heritage buildings. This process includes steps such as reviewing the suitability of modern tools, classifying the public survey, and the Pareto method. Esgusquiza *et al.* (2018) proposed an early-stage sustainability assessment (ESSA) approach to energy conservation measures, taking into account the development of energy performance of heritage buildings as a positive effect, combining the negative effects that the implementation of energy conservation measures could have. Gregorio and Seix (2017) presented the Urban Energy Renovation Index (UER) based on geographic location to conserve energy.

Most heritage buildings are abandoned, forgotten, unmaintained, dilapidated, and doomed to decay. This is a reluctant admission that a large part of heritage buildings are their residues. The reasons for this deterioration can be various, but the most common is that the building has not been used for a long time because it no longer meets today's needs, the heritage building has no owner, the goals and needs of the modern community have changed, lack of funding for maintenance, legal constraints and so on. As a result, the re-adaptation of buildings is presented as a common factor in preserving the past for future generations, thus ensuring the preservation and restoration of heritage buildings. Besides, most heritage building re-adaptation projects have combined „two different worlds", with churches being adapted for lofts, bars or restaurants, mansions for museums or offices, hospitals for schools or kindergartens, industrial buildings for shopping malls, hotels or, simply for car parking spaces.

Many researchers (Tokede *et al.*, 2018; Misilirsoy, Gunce 2016; Pszczolkowski 2016; Conejos *et al.*, 2016; Dyson *et al.*, 2016; Martins, Carlos, 2014) have examined the appropriate re-adaptation of heritage buildings in the context of modern urban development and the principles of sustainability of community needs and objectives, while protecting the environment, reducing carbon emissions and unnecessary waste of building materials and, most importantly, without losing the cultural, architectural, historical and spiritual values of the heritage building. Besides, Aigwi *et al.* (2018) examined the efficiency of the development of the re-adaption of historic buildings by analyzing the main factors and their change during the re-adaptation of a building. Also, it has been proposed to adapt the heritage building using the principles of an energy-efficient building (Cellura *et al.*, 2017) or sustainable development (Castaldo *et al.*, 2017). Conejos *et al.* (2017) presented the adapSTAR model (building and urban sustainability tool) for the future adaptation of a heritage building. The authors applied economic, social, and environmental values in developing this model. Blagojevic and Tufegdzin (2016) presented the renovation of industrial heritage buildings focused on sustainability approaches. The principle of sustainability consists of the economic, social, and environmental aspects and the heritage value of historic sites or buildings.

Nevertheless, the economic, environmental, and social benefits and the promotion of innovation of reusing heritage buildings, are highlighted. Economic benefits include reducing the cost of demolition of an existing building, design and development of an existing building, investment plan, market research, new building materials, productivity, use of building machinery, and energy consumption by renovating an existing heritage building and giving it new functions.

1.7.3. Methods of analysis of cultural heritage building management and reconstruction works

Historic cultural buildings are a symbol of cultural identity and the heritage of a particular community, which includes architectural, historical, cultural, religious values. Besides, historic heritage buildings account for a significant proportion of Europe's buildings, and their preservation is crucial for cultural, economic, social, and sustainable development. Preserving heritage requires the careful attention and experience of building owners, various professionals like heritage professionals, urban planners, historians, architects, restorers. And all this experience requires teamwork, cooperation, knowledge of structures, building materials, and equipment. Because of the preservation of heritage buildings, maintenance, and reconstruction work requires a lot of time and high costs. With this in mind, qualified professionals, scientists, and researchers are looking for a variety of methods that could be applied to properly and qualitatively preserve cultural heritage.

The construction industry is taking a step towards digital construction, which includes digital modeling of the building, better and more reliable communication between the participants in the construction process, lower costs of project preparation and time and, fewer errors in project preparation. Building Information Modeling (BIM) is a process that consists of creating and managing a digital description of the physical and functional properties of an object. During this process, an integrated information model of the building is created, combining the design parts of the building, its life cycles, from the project to its demolition.

However, this multimedia model approach is mostly applied to new construction projects. And traditional methods based on 2D exchange and information provided on paper are used for the preservation and management of heritage buildings. These methods prevent productive use of time and are not effective. With this in mind, the researchers proposed the Heritage Building Information Model (HBIM). This method is based on historical, architectural data and their identification, and the creation of a mapping system for heritage buildings based on laser scanning data. Laser scanning technology is used for modeling, 3D visualization, and imaging of heritage buildings.

The implementation of HBIM starts with the collection of geometric and technical data and is based on historical architectural data. Many researchers (Rodriguez-Moreno *et al.*, 2018; Osello *et al.*, 2018; Lopez *et al.*, 2017; Biagini *et al.*, 2016) have introduced HBIM as integrated workflow documentation, research, and modeling approach to ensure the retention of relevant information.

Nevertheless, an innovative approach to cultural heritage buildings' management has been proposed based on BIM technologies (Biagini *et al.*, 2016). In this context, attention is paid to problems such as parametric modeling of heritage buildings, laser scanning, 4D modeling of the site, the building and the maintenance work performed, and so on. Stober *et al.* (2018) presented a set of HBIM methods based on representation of heritage buildings, i. y. modeling, thermal and BIM scanning of these buildings. Also, different displaying options of the heritage buildings preservation, including ionization radiation presented in a digital dataset (Argenziano *et al.*, 2018). The Geographic Information Systems (GISs), City Information Modeling (CIM), and Building Information Modeling (BIM) programs were used to apply digital tools for construction, building materials, etc. properly. Anton *et al.* (2018) introduced the determination of 3D modeling efficiency for HBIM development. Besides, the complexity and deformations of heritage buildings are determined based on this modeling.

According to Hendriatiningsih *et al.* (2015), visualization of 3D surface models of the heritage buildings can be used to document, preserve, and reconstruct these buildings. Besides, modeling technology for 3D surface visualization of the cultural heritage objects is currently supported using laser scanning and robotic technologies. Also, the application of virtual reality models to heritage buildings is examined (Munoz *et al.*, 2014). Thanks to the application of these models, it is possible to assess the structures of heritage buildings and their condition. This means that a virtual model can be created using the structural results of each computational model, which provide information on structural stresses, strains, damage, and so on.

Sustainable development of the construction sector, including heritage sites, has been increasingly addressed in recent decades. It can be said that sustainable development is one of the most responsible directions, that include the preservation and modernization of heritage. The concept of sustainability has many questions that need to be answered to achieve the goals of sustainable development. Several of these goals are ften interconnected in terms of reuse, sorting, innovation, infrastructure, economic growth, urban and community development, and energy conservation, and good governance and legislation are always carefully considered in this process.

One of the possibilities of applying sustainable development in the field of heritage has been offered, taking into account the transfer of knowledge of sustainable heritage management (Seduikytė *et al.*, 2018). Using this method, the dimensions of sustainability were assessed as socio-cultural (new functions), socio-economic (tourism), and environmental (energy, comfort) factors. Franzoni *et al.* (2018) applied the LCA analysis method to assess the sustainability of the performance of heritage building conservation works. Also, the re-adaptation of heritage buildings was assessed in terms of the quality of the indoor environment (Al-Obaidi *et al.*, 2017). Aste *et al.* (2016) examined sustainable heating of a church in terms of energy savings, level of thermal comfort, the optimal indoor climate that would not damage church inventory with artistic value.

Also, Spyrakos (2018) proposed a new approach that would allow maintaining a balance between structural integrity and various constraints in the reconstruction of heritage buildings. This method allows a variety of reconstruction works to be carried out, where potential seismic hazards are required to be taken into account, and the cultural and archaeological aspects of the heritage building are assessed.

A comprehensive review of the literature shows that researchers have examined cultural heritage not only in terms of restoration technologies, materials used, or applications but also in terms of the impact of climate on heritage buildings, the possible consequences of earthquakes, and energy efficiency. Also, researchers have proposed a variety of methods and techniques that could ensure the preservation of cultural heritage buildings using modern digital technologies and concepts.

2. System of protected areas

There are many protected areas of different rank, purpose, size, different functional purposes, so it is necessary to know their classification according to the purpose performed and the protection measures used.

Currently, the comprehensive system of protected areas consists of the following categories:

4. areas of conservational protection priority where unique or typical natural and cultural landscape complexes and objects to protect. These include reserves (natural and cultural). Nature reserves and natural and cultural heritage objects (monuments);
5. territories of ecological protection priority are designated to avoid negative impact on protected natural and cultural heritage complexes and objects, or adverse effects of anthropogenic objects on the environment. This category includes ecological protection zones;
6. areas of restorative protection priority are intended for the restoration, increase, and protection of natural resources. These include reproductive and genetic fields;
7. complex protected areas where conservation, protection, recreational and economic zones are combined under joint protection, management, and use program. These include state (national and regional) parks and biosphere monitoring territories (biosphere reserves and biosphere reserves).

The requirements for protected areas establish public relations related to protected areas, the system, legal bases for the establishment, protection, management, and control of protected areas, as well as regulate activities in them (Department of Cultural Heritage, 2020).

2.1. Areas of conservational protection priority

Areas of conservative protection priority include reserves, nature reserves, and heritage objects/monuments. Reserves are protected territories created to preserve and research scientifically valuable natural or cultural territorial complexes, to ensure the natural course of natural processes or to maintain the authenticity of cultural values, to promote the protection of natural and cultural heritage regional complexes. Reserves determine the conservative primary purpose of land use by terminating economic activities there.

Nature reserves include protected territories created to preserve scientifically and cognitively valuable natural and/or cultural areas, their natural and cultural heritage territorial complexes and objects, landscape and biological variety, and the genetic fund. The preservation of the values located in these territories is ensured without terminating but by regulating economic activity. Restrictions on economic activity in nature reserves are provided by the laws of the Republic of Lithuania and the regulations of nature reserves. Nature reserves are divided into natural, cultural, and complex. According to the protected object, natural reserves can be geological, geomorphological, botanical, zoological, botanical – zoological, genetic. Cultural reserves are less critical for the aspect of biological variety conservation. Complex reserves include landscape and cartographic reserves.

FIGURE 2.1. Erosion effected hillfort

FIGURE 2.2. Land works at hillfort.

The concept of a natural monument was first time used by famous German geographer and traveler A. Humbolt in the XIXth century. Professor T. Ivanauskas was the first one to care for natural monuments in Lithuania. He thought that natural monuments could be old trees, stones, springs, and other objects of scientific, historical, and aesthetic value. Heritage objects (monuments) are also divided into natural and cultural heritage objects. Natural heritage objects can be geological, geomorphological, hydrographic, hydrogeological, botanical, zoological.

The Law establishes specific characteristics for protection and management of natural heritage objects on Protected Areas and regulations of natural heritage objects.

2.2. Areas of ecological protection priority

Areas of ecological protection priority are:

- **general environmental protection** zones (cities and resorts, the seaside and fields, groundwater well fields, surface water bodies, agricultural watersheds, and intensive karst);
- **buffer protection** zones (buffer protection of strict state reserves, state parks and state reserves, objects of heritage);
- **physical protection** zones (physical protection of objects of heritage, stations of state geodesy frame, electric power lines, gas and oil pipelines, communication lines and other infrastructure facilities);
- **visual protection** zones (visual protection of objects of heritage, astronomy observatories, airfields, and other infrastructure facilities; these are the areas in which a change of the environment can harm the environment of these facilities or hinder survey thereof);
- **sanitary protection** zones (sanitary protection of industrial and utility facilities, agricultural enterprises, and other economic facilities and infrastructure facilities).

FIGURE 2.3. A common view of the hillfort

FIGURE 2.4. A common view of the hillfort

FIGURE 2.5. Urban fragment

2.3. Areas of restorative protection priority

Areas of restorative protection priority (restorative and supportive) are the territories of preserved, restored, maintained, increased, and limited use of natural resources that are important for economic activities and society. These can be the plots for the reconstruction of berries, mycelium, herbs, fauna, peatlands, groundwater, and other renewable resources.

The purpose of genetic plots is to preserve seed trees and other types of natural genetic resources.

FIGURE 2.6. A common view of the hillfort

2.4. Complex protected areas

Complex protected areas cover the most significant area. Complex protected areas are the areas with natural and/or cultural integrity, in which the various protection priorities, as well as recreational and economic zones, are connected following the joint protection, management, and use program.

Complex protected areas are divided into State (national and regional) parks and Biosphere monitoring areas (biosphere reserves and biosphere reserves).

National parks are the areas established to protect and manage the natural (and cultural) landscape of national importance representing natural and cultural peculiarities of the country's ethnocultural areas.

Regional parks are the areas established to protect the landscape of the local significance and ecosystems of the natural, cultural, and recreational approach, to regulate their recreational and economic use.

The following functional priority zones are distinguished in state parks: conservation (reserve and reserves), ecological protection, recreational and economic priority, and other purpose zones. The regulations of parks determine the peculiarities of protection and management of state parks.

Regulations and other regulatory documents for activities in protected areas of national and regional parks are government-approved. They prohibit or restrict actions that may damage protected complexes and objects (properties), as well as recreational resources.

A national park, by a definition of the International Union for Conservation of Nature, is a large, complex protected area (PA) performing a nature conservation, recreational and educational-propaganda function. Territories with the ecosystems unaffected (slightly affected) by human activities, with the species of plants and animals and their habitats important for science; natural complexes and landscapes of scientific, recreational, or aesthetic interest are granted to the National Parks (NP).

NP is treated differently in different countries imposing national parks into Classical-American, European, African. All empowered by an international regulation that allows national parks to be established only insufficiently large, coherent, and minimum amended low pollution affected ecosystems, and only if real protection and effective control are guaranteed. Parks with the Conservative landscape protection combined with limited recreational use and limited economic activity are European-type.

Regional parks are related to national parks in terms of their purpose and functions, and together they form the state parks. The protection of landscape values, representing individual regions, is emphasized the most in regional parks. No reservation areas need to be separated there; resorts, recreation, and stationary rest areas are allowed. They are called specially protected areas due to their importance, conservation priority, and complex protection.

Complex protected areas also include biosphere monitoring areas – protected areas (biosphere reserves and biosphere proving grounds), established for global and regional monitoring of the biosphere, and the environmental experiments, as well as for the preservation of natural complexes.

FIGURE 2.7. Construction work at the protection area

2.5. The woodland key habitat (WKH)

Forests are one of the most important sources of biodiversity in our latitudes. The European Union (EU) has been supporting the development of balanced and sustainable forestry for several decades, where farmers support forest biodiversity, productivity, recovery potential, and viability. The purpose is to enable forests to play essential ecological, economic, and social functions now and in the future at regional, national, and global levels, without significant damage to other ecosystems.

Many European forests are “semi-natural”. There are still a lot of “semi-natural” forests in Lithuania. Even forests that are important from a nature conservation standpoint were planted or have been managed for a long time. Only small fragments of “ancient” or “primitive” forests have survived in hard-to-reach areas of more extensive production forests.

The woodland key habitats are biotypes of biodiversity value, unaffected (slightly affected) forest area with a high probability of finding endangered, vulnerable, rare, or protected specialized habitat species. Three groups distinguish the habitat species:

- indicator and site-specific species (mosses, lichens, mushrooms, plants, insects, etc.);
- key elements of nature (old trees, deadwood, rotting trunks, etc.);
- key aspects of the landscape (slopes, floodplains, streams, etc.).

The woodland key habitats have no defined size. It can be either a single tree or a small, only a few dozens of square meters of spring source, or few dozens of hectares of old forest. Some forests are close to the standards of the woodland key habitats and, in a few decades, will become areas with habitats and species that meet the standards of the woodland key habitats. Such forests are called potential woodland key habitats. Potential habitats are areas that can become woodland key habitats relatively quickly (within a few decades) if they are managed to maintain biological values.

2.6. Old towns

Research shows that the highest historical and cultural value of the old towns is the architecture of buildings, which in one way or another reflects not only the period of evolution of urban development but also the development of the history and culture of the country.

Gothic, Baroque, Classicism left their bright mark on the architecture of an old town. However, they were formed acquiring distinctive urban features.

The planned structure of old towns has developed during a long and complex process. It reflects the main directions of the planned formation of settlements and cities, depending on the period of (XIVth – XVIth centuries) evolution. The evolution of the planned structure of the old towns is closely related to the development of the country’s architecture, urban planning, and culture in general. The aim of the analysis of the evolution of the construction of old towns is to show the archaeological, historical, architectural, artistic, and urban value while defining the importance and scope of management.(History of Lithuanian architecture 1994).

One of the main tasks in managing old towns according to their function is to adapt architectural monuments to modern requirements so that the monuments of the past can continue their active life as an integral part of the developing city and historic center.

Making the old town as an attractive part of the city, adapting the old buildings and territories to today's requirements is an essential and complicated job that requires a lot of money and time. Complex archaeological, historical, architectural, economic, social, etc., studies need to be carried out before preparing a reconstruction project for any old town building or quarter, to avoid compromising the unique and specific construction of the old town.

2.6.1. Assessment of the condition of old town buildings

One of the most challenging tasks of modern urban planning is the old town buildings' (condition) assessment under technical and socio-economic factors that are hindered by social requirements and urban development perspectives. Therefore, the evaluation of their condition must be performed using a systematic method (Chart 2.1) (Kutut, 1994).

The presented scheme shows that the complex of technical and socio-economic factors consists of many measures, such as economic, social, historical, archaeological, architectural, demographic, etc. Therefore, to assess the condition of the old town buildings comprehensively is necessary to involve various specialists to study and analyze it methodically, provide the required conclusions and suggestions of the old towns' reconstruction methods as well as.

Before assessing the complexity of the annual increase of old towns reconstruction volume, it is necessary to perform a complex research to apply new technological methods, materials, install new equipment and mechanisms expertly for design and reconstruction works. The goal to accurately restore the old original volumes is not the only method of reconstruction (Chart 2.2) (Kutut, 1994). Preservation of as many authentic exterior and interior elements as possible is also important for the architectural monuments to not become newly created structures. It is also essential to provide them with the most suitable modern functions as well. Reconstruction practice shows that all this requires reasonable and accurate concepts, as each hasty conclusion subsequently requires additional work and funds to correct the errors.

The process of rebuilding an old town lasts for decades. Not only the buildings but also the quarters need to be thoroughly examined before the reconstruction of the old town begins, to enrich the functionally of the reconstructed or new buildings without damaging their architecture, specific old town structure. Therefore, this process itself must be based on scientific and technical progress.

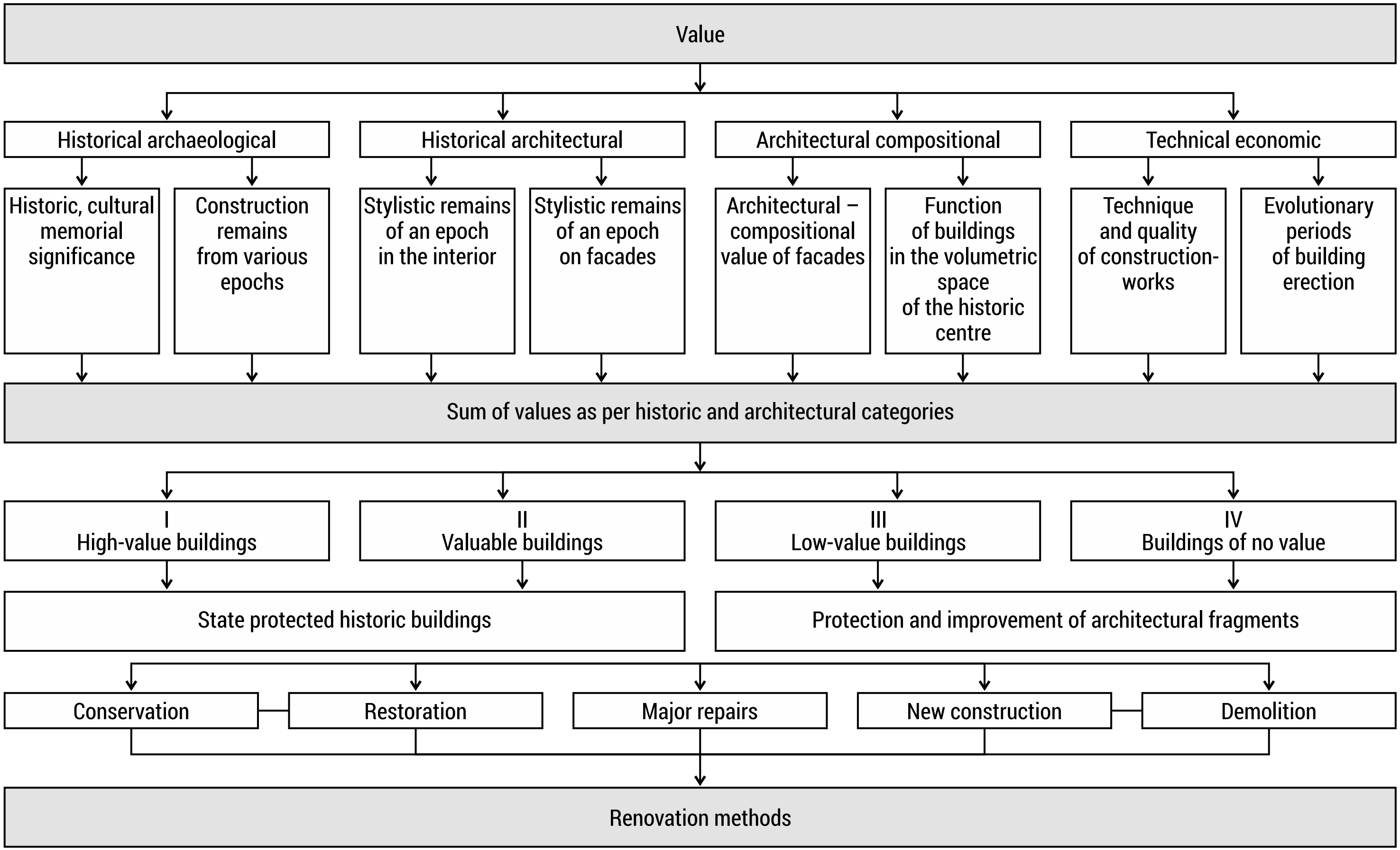


CHART 2.1. Evaluation of Cultural Heritage Buildings on the Basis of Historical and Architectural Categories

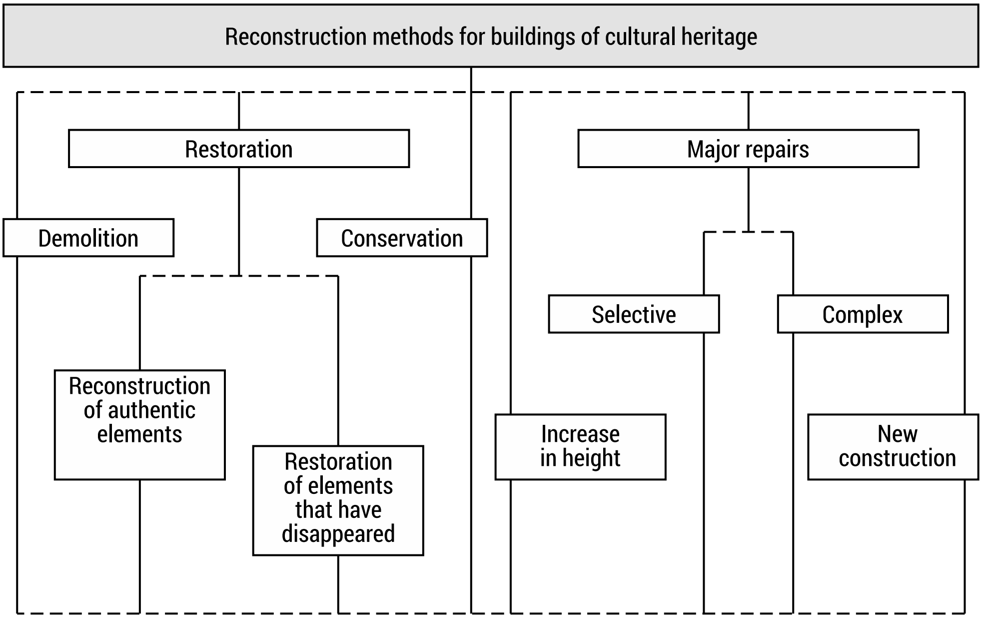


CHART 2.2. Reconstruction Methods for Buildings of Cultural Heritage

It is not enough to clarify and evaluate the former structural scheme of buildings. To identify the reasons for the decay of monuments and the lasting value of individual components of architecture in buildings it is necessary to single out authentic elements and separate them from the details of subsequent times and to find the ways to preserve the authenticity by selecting optimal techniques of reconstruction. Such a complex research is carried out solely for big and sophisticated objects, for instance, for a preparation of detailed designs of an old town regeneration and their quarters or individual monuments.

A detailed analysis of technical-economic and social-economic factors and quality has considerable importance for the reasoning of the accuracy of old town design solutions, the relevance of the scope of reconstruction, and for identifying efficiency.

The essence of depreciation of residential and non-residential fund of old town buildings lies in the fact that they progressively lose not only their operational but also original value because the used materials and structures slowly lose their initial quality characteristics, resulting in the deterioration of the performance of a building expressed by a physical, moral and general decline of a building (Radziszewska-Zielina *et al.*, 2017).

Buildings wear out both when they are physically used and not used at all. Physical deterioration is a loss of the initial characteristics of the buildings due to atmospheric hydrological-natural conditions, mechanical effects, also the internal processes of used materials.

The physical deterioration degree of the conditions of buildings is defined under specific conditions applying different assessment methods which determine the rate of deterioration that may be found out according to the following formula:

$$F = \frac{\sum_{i=1}^{n}(a_i \times l_i)}{100}, \tag{1}$$

where:

F – means physical deterioration, %;

a_i – stands for the comparative weight of structural elements in the total value of the building, %;

l_i – means the ratio of the price of structural elements to the cost of the entire building, %.

To determine the percentage of physical deterioration of old town residential and non-residential funds according to structural parts of buildings, the technical State of such parts shall be verified during the moment of re-evaluation, and the percentage of their wear and tear shall be identified. The principle of the approach is that the technical State of structural elements of a building has to be assessed, and the percentage of physical deterioration has to be evaluated first. Only afterward general deterioration rate of a building shall be calculated as an arithmetic mean (Formula 1).

One of the most important groups of capital value and durability of the buildings of old town residential and non-residential funds is not only physical but also moral deterioration of buildings. Lately, the increasing focus has been put on the moral deterioration of buildings. There are two forms of moral deterioration. The first one shows the reduced value and the second one – the fulfillment of comfortability and service of engineering networks.

When determining the percentage of moral deterioration of old town buildings, it is necessary to take into consideration the following factors: defects in the internal arrangement of the structure, defects of engineering networks and of equipment inside the building as well as many other effects that fail to meet operational, living, hygiene and sanitary requirements (Turskis*et al.*, 2017).

The level of the engineering network service of all buildings of old town private funds is very different and unsatisfactory and even very poor. Therefore, the sanitary and hygiene standards have to be taken into account that when identifying moral deterioration of buildings, not only their functional purpose. Regardless of the initial use of a building and trying to adapt it for a new function blindly, we start rearranging it, making new openings, designing horizontal and vertical links, which form the reconstruction of a building considerably more expensive without a doubt. That's when old towns lose architectural economic and moral value also (Radziszewska-Zielina *et al.*, 2017).

The moral deterioration of buildings depends on the advancement of science and technology in the field of construction and the urban sector. Moral deterioration is determined by the latest technical solutions of buildings or some aspects of buildings (volume-related, arrangement-related, structural), new sanitary, and hygiene standards. Moral deterioration (M) is calculated according to the formula below:

$$M = \frac{\sum_{i=1}^{n} (q_i \times d_i)}{100}, \tag{2}$$

system, district heating, etc.), %;
d_i – stands for the value of the missing component of facilities in the total value of a building, %.

It is usual to determine the value of residential and public buildings based solely on their physical state, i.e., the value of a building is equated to its material value. Meanwhile, drawbacks of the superficial defects, hygiene conditions, and exterior disadvantages, i.e., their moral deterioration, are often not taken into account at all, or it is considered superficially. Sometimes old and dilapidated buildings are left in reconstructed quarters of the old town. They are not reconstructed or chosen for the overhaul either, though living or working conditions are certainly inappropriate both in terms of hygiene, sanitary conditions, and technical-economic situation. In the complex evaluation of physical and moral deterioration of old town buildings, the networking into one index of general deterioration could reflect not only the percentage expressed a degree of deterioration but also indicated their material and monetary value (Kaklauskas *et al*., 2011).

General deterioration of buildings (B) is calculated according to the following formula:

$$B = F \div M - \frac{F \times M}{100}, \tag{3}$$

where:
F – stands for physical deterioration, %;
M – means moral deterioration of buildings, %.

A complex assessment of the state of old town residential and non-residential funds has a significant meaning not only for justification of the effectiveness of reconstruction but also for the amounts of replacement value and amortization deductions, which economically significantly help cover the cost of buildings' deterioration (Kaklauskas *et al*., 2012).

Buildings of an old town residential and non-residential funds deteriorate physically and morally in line with their reducing replacement and current value.

Replacement value of buildings is expressed through reproduction prices of the residential and non-residential funds, i.e., evaluating them when the inventory is taken and they are priced.

Present and residual value express the value of residential and non-residential funds after the deduction of their depreciation and after the assessment of the general deterioration of buildings is carried out. The difference between their current value and the replacement value will amount to the degree of their deterioration. The expression of present value is illustrated in formula four below:

$$Dv = Av - \frac{Av \times B}{100}, \tag{4}$$

where:

Dv – means the current value, EUR;
Av – means replacement value, EUR;
B – stands for general deterioration, %.

Pricing of buildings at their present value, given their deterioration, enables individuals to determine the actual value of residential and non-residential funds at the required moment.

When identifying the appropriateness of reconstruction, one of the main technical-economic factors is the assessment of the State of buildings' durability since the balance of strength of structures is directly proportionate to their physical deterioration. Balance of buildings' longevity can be calculated according to the following formula:

$$IL = (1 - \frac{100}{F}) \times In, \tag{5}$$

where:

F – means physical deterioration of buildings (%) according to the groups of capital value;
In – means normative durability of the group of buildings' capital value expressed in the number of years:

TABLE 2.1. Recommended Normative Durability

Indicator	Unit of measurement	Groups of capital value									
		Residential fund				Non-residential fund					
		I	II	III	IV	I	II	III	IV	V	VI
Normative durability	Year	150	125	100	50	175	150	125	100	80	50

Following the reconstruction of buildings and after the removal of physical deterioration, their durability is again restored to the normative level or in often cases even exceed the normative strength, where a complex overhaul of buildings is performed (foundations and walls are reinforced, new overlaying structures are installed). It is transposed to a higher group of capital value. Today scientific and technical achievements are widely used in reconstruction; for this reason, the attribution of old town buildings to higher-level groups of capital value is entirely practicable.

From the methodological point of view, based on technical-economic factors, it is reasonable that the structures of buildings that have resisted the effects of time undergo significant repairs, and buildings are adapted to the modern-day needs, overlaying structures of buildings are replaced, structures of roofs, staircases are replaced, etc. Modifications and replacements are prompted by a deterioration of wall structures, new construction, and fire safety standards, requirements of contractors as well as a low balance of buildings' durability. When reconstructing buildings, the group of the capital value of buildings has to be increased to the maximum, i.e., and a reconstructed building has to meet all modern-day sanitary and hygiene as well as urban design requirements and people's needs (Radziszewska-Zielina *et al.*, 2017).

To select buildings of old town residential and non-residential funds for significant repairs, it is necessary to not only assess them taking into consideration technical-economic factors but to also identify the coefficient of relevance/appropriateness of reconstruction (Kt) according to the following formula:

$$Kt = \frac{\frac{Av \times B}{100} \times In}{Av \times IL} < 1, \tag{6}$$

where:
Av – means replacement value, EUR;
B – means general deterioration, %;
In – means normative durability expressed in the number of years;
IL – means a balance of strength.

The structure of the formula shows that the reconstruction of buildings or a residential area (quarter) is relevant and appropriate if their coefficient is lower than 1 ($Kt < 1$).

The application of categories of deterioration in buildings in the group of technical-economic factors does not mean at all that no assessment of old town residential and non-residential funds is needed according to physical, moral, and overall deterioration and groups of capital value. The factors mentioned above form the basis for the identification of categories of deterioration in buildings as follows: **the first** category contains buildings that have the capital value group from I to III and deterioration rate of which is no more than 35%, **the second** category means buildings with capital value group from II to IV and are deteriorated from 36 to 50 percent, **the third** category includes buildings with capital value group III and IV and are deteriorated from 51 to 65%. **The fourth** category means buildings with a capital value group from IV to VI whose deterioration exceeds 65%. Such a categorization of buildings according to the types of deterioration helps to carry out a more accurate analysis of the State of deterioration in buildings, find deterioration coefficients, and, based on them, determine the price of reconstruction and its relevance taking into account technical-economic factors (Kutut, 2014).

The assessment of the state of buildings according to deterioration categories leads not only to the determination of the state of deterioration but also to the identification of reconstruction approaches with a view to technical–economic factors.

Buildings contained in the first category of deterioration can be characterized as of a good state, featuring no failures and deformations except for minor defects that do not affect the usage of the building and that can be removed through routine maintenance (running repairs), and in some cases – subject to the state of deterioration in a building – by performing significant selective maintenance. The second category of the state of deterioration in buildings shows that structural components are appropriate for further use after necessary considerable repairs have been carried out. The third category of depreciation means that the state of buildings, the main load-bearing structural components, and overlay structures are appalling, and the use of buildings is possible solely following their significant repairs. The state of buildings attributed to the fourth category of depreciation is considered as being in an emergency state. To continue using them, protective work has to be carried out, or worn-out structures have to be replaced. Further use of the latter buildings is allowed solely in exceptional cases if they are considered to be the architectural monuments. In all other cases, it would be reasonable to demolish buildings of this category simply.

Technical-economic factors of a complex assessment of the state of buildings of an old town residential and non-residential funds determine the character and necessity of reconstruction. Indeed, such technical-economic factors as physical and moral deterioration of buildings, replacement and present value of buildings, group of capital value, provision of engineering networks, etc., still play an essential role in determining the nature of reconstruction of an old town. However, if the state of buildings is not assessed in a complex manner, i.e., according to technical–economic and social-economic factors, no complex reconstruction of an old town is possible; for this reason, when evaluating the degree of development, it is necessary to take into consideration many physical architectural and aesthetical factors (Turskis *et al*., 2016).

A lot has been achieved in the development of an old town reconstruction. However, it should be noted that social-economic issues of the assessment and planning of reconstruction that have a direct effect on the extent of an old town reconstruction, its price, and efficiency have been tackled with a lack of consideration from different angles. It is necessary to take into account not only technical but also social-economic factors when planning such activities.

The evaluation of the evolution of an old town buildings enables the identification of trends in construction development in specific periods, which are similar but have developed under different political and economic conditions.

Assessment of the old town development based on the categories of historical--architectural value shows which part of buildings belongs to one or another architectural category, and which of them a similar reconstruction approach can be applied to.

The analysis of the value scheme (Chart 2.1) illustrates that grouping of old towns according to historical–architectural categories is possible in cases where buildings are assessed in a cross-cutting manner taking into consideration technical, social and economic factors, where reference is made to scientifically reasoned recommendations both to protect architectural monuments and reconstruct them as well as plan new construction in the territory of an old town. For this reason, the evaluation of buildings according to historical–architectural categories helps to find effective methods and forms of an old town regeneration to preserve better not only valuable buildings but also the overall specific development, incorporate the entire old town into the composition of a modern city in a comprehensive manner and provide city dwellers with normal working, life and rest conditions.

It is universally known that the beauty of the development of an old town is determined not only by the quality and quantity of the architecture of buildings but also by the silhouette, i.e., the harmony of heights of buildings. The planning of height and space in the architecture of an old town development is an integral process. The height of buildings has been the basis that embodied the originality and specific features of composition in architectural ensembles. It is determined according to the following formula:

$$X = \frac{\sum_{i=1}^{n} x \times f}{\sum_{i=1}^{n} f}, \tag{7}$$

where:

X – means the average height of buildings;
x – stands for the number of floors in buildings;
f – indicates the number of buildings.

The results of the survey of the height of buildings in old towns show that the average height of buildings is from 1.45 to 2.15 stores.

The silhouette of an old town buildings is an organic totality of developed and open spaces. The life and working conditions of old towns can be improved by finding the right quantity and quality ratio between the developed and accessible, asphalt, concrete, and grass-covered areas. Thus, it is necessary to assess and plan both the management of developments and the free regions, in particular, green areas, in all phases of reconstruction. When developing the system of squares and plantations of old towns, consideration has to be taken of the following:

1. The lack of plantations in the residential territory of an old town can be compensated by increasing the number of plantations of public purpose and the areas of other individual spaces.

2. The critical components in the system of the open regions of old towns are squares, backyards, former plantations of gardens, and residential territories that have gradually developed over time.
3. Squares and green areas that have retained their full or partial architectura-artistic value have to be analyzed comprehensively and restored.
4. It is reasonable to include the system of plantations into all territories which previously had green areas or where undeveloped open spaces have gradually deteriorated. It would be fair to regenerate them as spatial elements of old towns.
5. The system of open spaces being developed has to be necessarily connected to the routes of pedestrian movement and aim at the variety of conditions for recreation.
6. Narrow functional specialization is necessary for the system of an old town squares and plantations that would determine a more even distribution of visitors and would protect objects from overloading/overcrowding.

The practice has shown that a complex reconstruction and adaptation of an old town development for the modern-day needs according to all scientific and technical requirements is hard and big work which requires decades and considerable finances. Before starting a restoration, a thorough and cross-cutting examination of the state of buildings is necessaryto do to prevent any damage to the specificity of a cultural monument due to restoration activities, enrich a monument in terms of architecture and function, i.e., such utilitarian purpose has to be found which could make it accessible to everyone, i.e., city guests, tourists and city dwellers (Radziszewska-Zielina*et al*., 2017).

3. Cultural heritage objects in terms of sustainable development

Renovation and revitalization of cultural heritage objects is an essential axis for sustainable development. Cultural heritage can be used to strengthen the local economy, attract investments, highlight local distinctiveness, and the added value of the real estate in a particular environment.

The reconstruction of cultural heritage objects may be more expensive than initially estimated by the owners. However, frequent research suggests that the increased estimates during the work process may be lower than the construction of new objects that do not create as much economic value as the historic buildings. Energy resources, the abundance of materials used, and the waste generated in the construction of new buildings provide fewer advantages than the resurrection of an object to life in terms of sustainable development. Cultural heritage buildings and areas are rich in materials suitable for reuse. The reuse and savings of energy and materials are a critical aspect of these times of energy crisis.

The reconstruction of historic buildings also reduces the amount of gas generated during construction, loading the landfills, and household waste emissions, which directly affects the greenhouse effect indicators.

Reinvestment in historic sites ensures the preservation of inherited buildings, spaces and places for future generations. At the same time, the reconstruction of protected objects allows to incorporate new historical layers, reflecting specific talents, aspirations, and eras in the newly restored object. This way, different historical eras interlock in one object. The preservation, renovation, and reconstruction of historic buildings reflect the success of sustainable development.

Strong economic motives drive the reconstruction of historic buildings. The benefits of renovated heritage objects are monitored not only for individual entities but also for more extensive areas or communities. The inclusion of cultural heritage objects in global regeneration schemes is becoming an essential catalyst for sustainable development. Successful regeneration of heritage objects has a far-reaching effect that goes beyond the site and has a positive impact on society and the city.

Theoretically, the regeneration of a cultural heritage object is necessary to avoid a decline of its physical, economic, and social characteristics. It is also essential that the renovation of a cultural heritage object in urban spaces must integrate into the urban environment and its development. What is a successfully developed urban environment? What do many people see as thriving urban environment components? Main elements are:

- streets, not roads;
- the variety of opportunities offered by the urban environment;
- variety of building styles;
- reduction/absence of traffic flows;
- public spaces;
- well-maintained buildings and sidewalks;
- open opportunities for the community to influence urban area;
- exciting design solutions in specific areas;
- ensuring security;
- maintaining authenticity as a counterpoint to the unnaturalness.

Assuming the totality of elements of a thriving urban environment, the overall impression and atmosphere in a particular urban area are more important than individual buildings. However, individual buildings can become a reference point creating an atmosphere of a thriving environment. Heritage objects often help to regenerate the surrounding environment by incorporating the historical and economic value of the site into the whole surrounding of the object. Reconstruction of historic buildings can create an environment where people want to work, live, or visit. The dimension of successfully developed historical places, districts, or quarters becomes the desire of people to be in these historical-cultural environments (Radziszewska-Zielina *et al*., 2017)

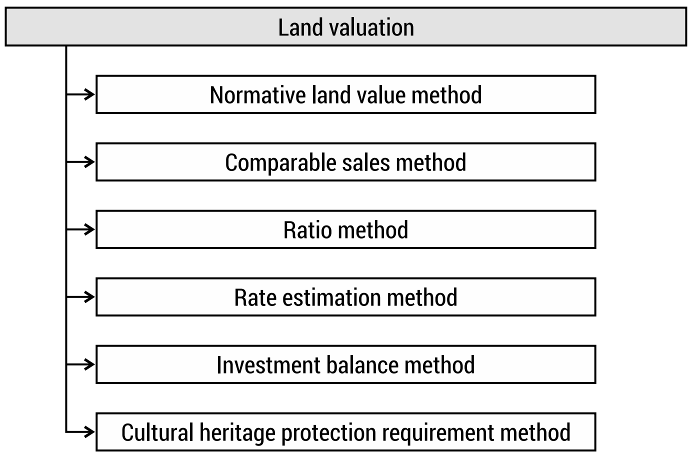
People are reaching out to such places because of:

- different spaces, building types, sizes and variety of uses;
- interesting architectural details;
- beauty of architecture;
- local specifics;
- associations with the past;
- richness and warmth of design;
- physical manifestation of urban transformation;
- positive social atmosphere;
- historical meaning of the place;
- quality of life.

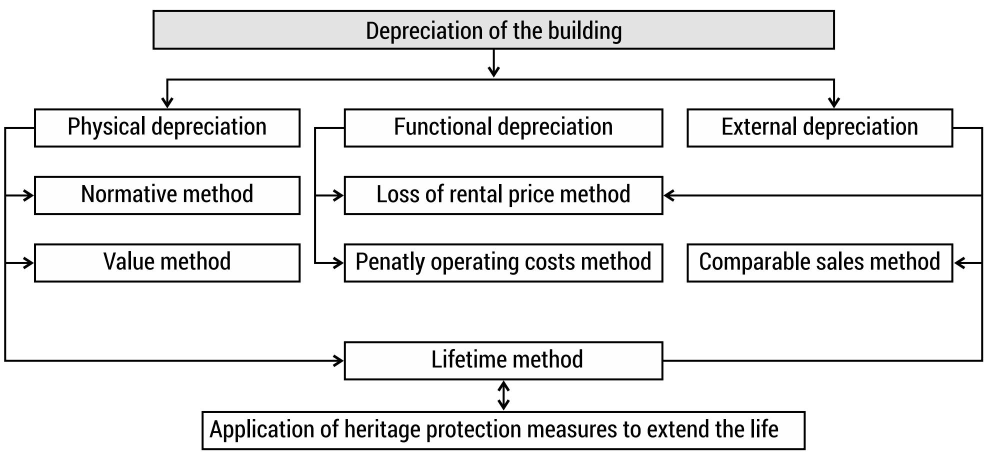
To achieve coherence between heritage preservation and adaptation to the needs of the investor, it is important:

- to establish the main criteria for conservation and development following the concept of urban territory;
- to improve the attractiveness of heritage protection territories for investments under the legal bases for the cultural heritage protection;

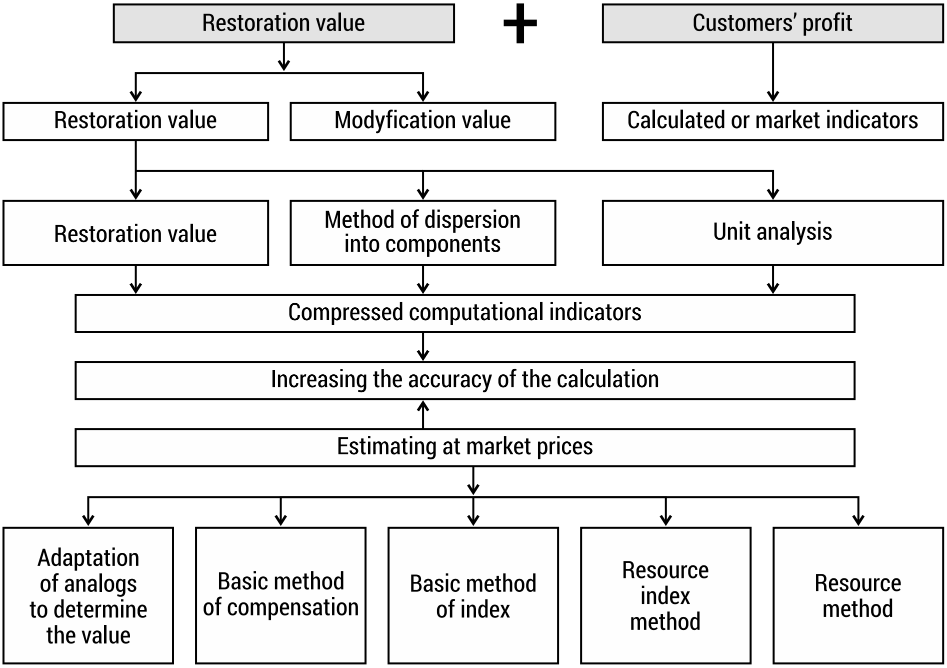
- to enhance the forms and methods of management of cultural heritage and their areas;
- to involve the public, and in particular the local citizens, in the preservation and integration of cultural heritage objects into the socio-economic life of the city or territory;
- promoting tourism to ensure a return on investment in the maintenance or restoration of monuments;
- to use the brand name of monuments in the historical area of districts and cities, thus increasing the value of the real estate, which ensures the return of funds invested in restoration;
- to take into account the specifics of real estate valuation in cultural heritage areas when estimating the value of land and the depreciation of buildings.



SCHEME 3.1. Land value (Kaklauskas et al., 2012)



SCHEME 3.2. Depreciation of the building



SCHEME 3.3. Specifics of real estate valuation in cultural heritage areas (Kaklauskas et al.2012)

FIGURE 3.1. Urban fragment

FIGURE 3.2. Urban Fragment

FIGURE 3.3. Historical building

Cultural heritage management works must be carried out using particular technologies to ensure the preservation of authenticity.

In the protected area for public knowledge and use it is prohibited:

1. to destroy or damage in any way the valuable features of cultural property indicated in their cultural passport;
2. to develop any constructions in the territory and protection zone that would obscure the object or objects of cultural heritage in height, scope or expression and overshadow their overview;
3. to destroy or damage memorial plaques, information stands, or landmark of cultural heritage property or areas;

4. construction works that diminish valuable features, such as: to adapt a cultural heritage property to other uses than those of the cultural value passport; to increase the intensity of use of protected structures – to build extensions, additional floors, new attics, to form new planned structure and otherwise eliminate the signs of authenticity;
5. the consent of the authority responsible for the protection of the cultural heritage area must be obtained in order not to adversely affect the valuable features of a protected object or area, if:
    1. there is a plan to divide a protected object or plots located in its territory, to change their boundaries, except in the cases established by the Law on Protected Areas;
    2. there is a plan to change the method and nature of land use, construction development regime, the purpose of buildings or structures in the territory of the protected area;
    3. there is a plan of new construction development works in the protected area and protection zones, to change riverbeds, change existing and install new groundwaters, change the relief, establish new or expand existing quarries, plant greenery that will obscure valuable properties;
    4. there is a plan to install commercial advertisements, outdoor antennas, and other technical devices outside the protected buildings.

3.1. Peculiarities of evaluations of the real estates in cultural heritage territories

The primary mission of the State is to preserve the cultural heritage and pass it on to future generations as a guarantor of the nation's survival, as an integral part of the landscape and image formation remedy, creating conditions for the public to get to know and use it.

The immovable cultural heritage is part of the country's property. Mounds, ancient ramparts, other old fortifications; ancient places of residence and workshops, ruins and remains of ancient buildings; alcoves, sacred mountains and other places of ancient religious worship; altars, stones with bowls, feet, inscriptions, and other signs; earthenware, slabs, and others old roads; burial mounds, cemeteries, and other ancient burial sites; dormant cemeteries and soldiers' cemeteries have cultural and social significance and are registered as immovable cultural property.

Cultural property can be "buildings and their complexes, ensembles, and sites" and other objects of cultural value and social significance. Laws on Protection of Immovable Cultural Properties explain what the constructions, their dependencies, and areas are:

- structures – architectural, monumental art, technological, and other immovable human works, their parts, and remains;

- dependencies – statutory, functional, or historically related movable creations related to structures;
- areas – historical and cultivated topographical areas and places of the landscape.

The European Convention for the Protection of the Architectural Heritage and other legislation anticipates that cultural heritage, and in particular architectural heritage, is an indispensable expression of the richness and diversity of Europe's cultural heritage, an invaluable witness to our past and a common asset for all Europeans. Therefore, it is essential to pass on the system of cultural symbols to future generations, to improve the urban and rural environment, and thereby to promote the economic, social and cultural development of the State and regions by reaching agreement on standard policies for preserving and enhancing the architectural heritage. The State undertakes to prevent the destruction, damage, or demolition of protected values. Takes to require the submission to the responsible authorities of any plans for the demolition or alteration of monuments already in protection or in respect of which protection procedures have been initiated, and of any projects affecting the environment, group of buildings, part or area of such monuments; it is planned: to demolish buildings, to build new buildings, to make substantial changes that would damage the specificity of buildings or the area.

By ratifying the European Convention for the Protection of the Architectural Heritage, the State undertakes to implement an integrated conservation policy that:

- would define the protection of the architectural heritage as a key objective of urban and rural planning and would ensure that it is taken into account at all stages – the development plans and permission for works;
- would promote architectural heritage restoration and maintenance programs;
- would consider the conservation, promotion, and enhancement of the architectural heritage as an essential part of cultural, environmental and planning policies;
- would allow the preservation and use of specific unprotected but valuable building due to their location in the urban and rural planning process, for their quality of life;
- would promote the application and development of traditional skills and materials as a critical factor in securing the future of the architectural heritage;
- would encourage the use of protected objects in assessing the needs of modern life;
- would adapt old buildings to new needs as much as possible.

The State is committed to protect and manage the landscape and cultural heritage as a component by planning the measures to ensure the rational use of natural resources, ecological balance, formatting the natural framework, and preserving the natural and cultural heritage values. In implementing the integrated sustainable development policy.

These all are legal obligations, but it is essential to know the cultural heritage preservation condition as a necessary component of sustainable development. Cultural heritage must be used as one of the national security components. The heritage is doomed to destruction when only "preserved" and not adequately handled by the community. It currently appears in some of the protected regional parks or reserves, where overly restrictive human activities change the landscape, natural, and biodiversity situation. However, all this should be preserved, as the cultural heritage for future generations.

The use of cultural heritage begins during spatial planning and, the issue of integrated and sustainable development should already be addressed at the county or municipal level of the general plan following the legislation. However, today the requirements for cultural heritage objects and their complexes are established by special plans or by law. For the areas that include all urban structures, the conditions are determined following the Law on Protected Areas by other legal acts – regulations. Therefore, at the stage of preparation of the general plan, we cannot state the requirements applicable to cultural heritage objects established by special plans cannot be stated, as they have not been prepared yet. Special plans must be developed for all The State and municipal protected objects of over seven thousand that we have today, and only two dozen specialists in the country with mandatory relevant certification but not enough finances (about seven hundred million **Eur)**. The general plan notes that the requirements for cultural heritage objects will be set out in special plans, which is an unknown future.

The territories are managed in accordance with the relevant territorial planning documents, where it is provided that the objects are administered in conformity with the established heritage protection requirements, regulations of administrative construction work, and heritage management regulations. Such a legal regulation, when a manager will not be able to manage the territory without a special plan, that is not clear when it will be prepared due to lack of funds, creates preconditions for the extinction of cultural heritage objects. Failure to rehabilitate the territory creates obstacles to the management of buildings in the area and often causes damage to the cultural heritage site.

It is required for the boundaries of the territory of a cultural heritage object to coincide with the limitations of plots or their parts, which are objects right in rem. In cases where limits of the area of a research-based cultural heritage object do not correspond to the limits of the object rights in rem, the responsible institution shall organize and finance the legalization of part or parts of the plot as new objects' rights in rem. Such legal regulation makes no sense and requires additional, unjustifiable budgetary resources. First of all, the territory of a cultural heritage object is delimited bases on researches, whereas delimiting the object rights in rem is market. The Department may organize and finance the identification of the boundaries of the territory of the cultural heritage object with the boundaries of the object of rights in rem. Still, there is no guarantee that the boundaries of the object of rights in rem will not be changed again.

It should be noted that the owner of the object of rights in rem has the right to dispose of his property, i. e., to assign it to another person or to acquire it from another person, thereby reducing or increasing the boundaries of the objects of rights in rem. After such transactions, the boundaries of the territory of the cultural heritage object will not coincide again with the boundaries of the object of rights in rem, and the Department will yet have to organize and finance the legalization of new objects of rights in rem (Cultural Heritage Center, 2004).

The enshrined Protection Regulations as a document regulating the management of the territories of protected objects, protected areas, protection zones, and the activities developed therein would achieve that:

- the proprietors of cultural heritage property published or declared protected, as well as of the other objects registered in the Register of Cultural Heritage, would be aware not only of the valuable characteristics but of the heritage protection requirements of the objects they own as well. Thus, the scope of works violating cultural heritage values and heritage protection requirements will reduce.;
- there would be no immediate need to prepare a large part of the special territorial planning documents for the protection of immovable cultural heritage (from now on – territorial planning), which is a long and costly for the States' budget. The integrated planning should be estimated preparing General plans anticipating the possibilities for development;
- it would be cheaper and shorter to introduce the protection regulations;
- the content of the protection regulations would correspond to the content of the territorial planning (in the part of solutions), the established requirements would be valid until the preparation of the territorial planning.
- private and business investments would not be hindered, as is currently.

3.2. Special spatial planning and solutions for immovable cultural heritage protection

Many interrelated factors, such as economic, social, political, legal, human, and cultural, are involved in the creation of a sustainable spatial development system.

The implementation of the protection of immovable cultural heritage through special territorial planning documents – special plans, clearly reflect and illustrate the criteria of maximum preservation.

It is not contested that the immovable cultural heritage protection is one of the integral aspects of sustainable spatial development. The uphold, use, and management of inherited values induce the activities of tourism, education, investment, increases and enriches the potential of spatial development, which integrates all aspects of development. The wise management and use of immovable cultural heritage assets benefit all market participants, from investors to consumers.

The current system of protection of immovable cultural heritage could be considered as contained, centralized, and expertise. The State (in part – municipality) is the one found:

- to be responsible for heritage conservation;
- to finances the preparation of special plans and to organize them;

- to coordinate the prepared documents and to be accountable for their execution;
- to penalize for improper protection and use of immovable cultural heritage values, even though most of the values have been privatized or returned to the owners and no longer belong to the State.

It is obvious, that the State does it all alone, although practice shows the opposite phenomenon when a private investor is engaged in valuables management, and the State performs punitive police functions in most of the cases.

All Cultural Heritage objects are protected together with the squatted and designated territories, that are inseparable. The immovable cultural heritage assessment councils formed by the subdivisions determine the significance of immovable cultural values, the valuable properties of cultural heritage objects or areas, and the boundaries of territories (Department of Cultural Heritage, 2020). The main reason is the lack of certified specialists in the subject.

After defining the boundaries of the territory, after declaring the object protected, a special plan is prepared – a territorial planning document (TPD). There are several types of Special Planning documents:

- schemes of cultural heritage networks;
- plans of the boundaries of cultural heritage territories (territories, areas of cultural heritage objects) and protection zones;
- plans for the management of protected areas and protection zones (planning schemes);
- land tenure plans for protected objects and areas;
- heritage management projects of protected objects.

Publicity of the planning process is one of the main components of the preparation of territorial planning documents, and discussion of restrictions with the society is unprecedented. Partial financing or otherwise compensating (tax reduction, financing of specific works, etc.), the expenses of the real estate users, and owners who have restrictions appears to be a worldwide practice.

The main feature of the integration of special plans is that separately prepared territorial planning documents become the conditions for the preparation of the general and/or detailed plans. Neither general nor detailed plans can define heritage protection requirements. These separately prepared documents make the preparation of a single document for sustainable development difficult.

The heritage protection requirements imposed in the special planning documents are mandatory for general, special, and detailed spatial planning documents.

General plans are one of the critical documents defining sustainable development.

The main assumptions of the protection of immovable cultural heritage must be reflected in the prepared general plans that will allow for the proper integration of cultural heritage protection aspects and ensure the preservation of immovable cultural heritage values.

Market trends and fashions are not the ones to rely on when monitoring the development of the real estate market and taking into account the cyclical aspect of the economic and real estate sector. The real estate sector is characterized by cyclical supply and demand, whereas property in the territory of cultural heritage must also be assessed from the aspect of heritage protection.

Cyclical changes in the real estate market are the result of economic, financial, and social phenomena that shape the factors that determine the demand and supply of real estate. Thus, it is impossible to assess the real estate sector in cultural heritage areas without identifying its role in the market-economy Central and Eastern European countries first, which are rapidly integrating into the markets of developed Western European countries.

3.3. Real estate development on cultural heritage territories

The system of protected areas, urban structures, priorities applied, must be explored to assess the place of the real estate sector in cultural heritage areas in the market economy and its development opportunities. The broader aspect of the economic structure must be analyzed, as well as.

Examining the location and trends of the real estate sector, it becomes is clear that real estate development caries out five main functions:

- **first** – real estate, including infrastructure, should be considered a factor of production as a capital base for the development of goods and services;
- **second** – households use real estate for their domestic, leisure and social activities in their free time;
- **third** – individuals with financial resources use real estate for short-term and long-term investments;
- **fourth** – real estate can become part of the capital market, converting it into money by selling or obtaining a loan secured by real estate;
- **fifth** – the performance of the real estate sector has a significant impact on the economy and trade due to the highly developed material and financial relationships that shape the demand for other goods and services in the local market.

All five functions are applicable to real estate development in heritage areas in the real estate sector. However, determining the value of the property and the possible options for its disposal, it is necessary to take into account the factors of the specifics of the cultural heritage area.

The real estate sector plays the role of land “supplier” for the economic activities, human habitation, and construction sites, and the reconstruction of cultural heritage sites for the most developed market economies. It is necessary to monitor the changing needs for land and premises of producers and consumers constantly. If you assess these needs in terms of the purchasing power of producers and consumers, you will be able to get an overall picture of the real estate demand. Monitoring and analyzing the real estate market to predict its possible changes requires not only to monitor its performance constantly, i.e., prices, rents, and their variations, but also to assess potential changes in employment and territorial development, which are known to be determined by social and economic processes. The State's view in real estate development, preserving cultural heritage is essential.

The creation and expansion of an efficient and active real estate market, serviced by professionally trained staff, is the only way to adjust the real estate increase inherited from the former economic system. Besides, this way, the use of available real estate resources can be rationalized by increasing their profitability and decentralization. A properly functioning real estate market must enable efficient users to purchase the premises or land, rent it, or take it over from inefficient entities in specific locations they need. Multiplying the transactions with positive results by a large amount of real estate that needs to be "reallocated", it can be noticed that such a course of activity would have a significant impact on the development of the country's economy. This can only be achieved by creating effective search engines for efficient real estate users, which cannot function without the support of a free and transparent real estate market and highly qualified property valuation, management, brokerage, financing and consulting professionals.

Based on the facts, the real estate market is not independent from the influence of other sectors of the economy. On the contrary, it "serves" the processes taking place in the fields of employment and housing. This market will function effectively only if the legal framework governing its activities is set up, and the professionalism of real estate service providers is ensured. The professionalism of real estate market experts is considered a necessary but not sufficient condition. The efforts of highly qualified workers alone were not enough to overcome the crisis in the real estate market in Western Europe in the 1990s. This best confirms the thesis that the real estate market is not independent from the influence of other sectors.

On the contrary, it is highly dependent on the general phenomena and pace of development in society and the economy. The challenges facing real estate markets in developing countries are closely linked to the specificities of their economic, social, and political systems. External factors, which, unfortunately, are often overlooked by many real estate market participants, form an integral part of its mechanisms and knowledge. Besides, it is often forgotten that the capital of investors promoting the real estate market should be seen not only as an investment in the real estate itself but also as a capital investment in the economic development of the State, region, city, or specific cultural heritage area. The attractiveness of a property depends on its location concerning many external factors that change over time, which affects both the value of the property and its trade.

Increasing the role of the real estate sector in cultural heritage areas can only be achieved by developing and activating the market for this property, stimulating demand and supply, and reducing barriers to the conversion and efficient use of heritage sites. Due to the situation in the real estate sector, the real estate market procedures should be simplified as much as possible to maintain its development, so that legal and tax systems do not hamper the changes required in the ownership and management of the property (Radziszewska-Zielina*et al.*, 2017).

In the real estate development of cultural heritage areas, the public authorities' role of play should not be limited to inspections and prohibitions. Still, it should assist real estate market participants and, at the same time, contribute to the preservation of as many heritage buildings as possible. First of all, the spatial planning should be considered by public authorities, as well as the necessary studies of complexes and individual heritage buildings in old towns. With the historical, architectural, archaeological, and other essential research results, real estate proprietors would be able to anticipate the necessary costs of preparing buildings for the real estate market, taking into account specific heritage requirements in a particular area.

Overall, real estate can be divided into:

1. property: apartments, houses, tower blocks;
2. non-residential premises: shops, offices, industrial objects, shopping centers, special-purpose objects;
3. land: plots for the construction of residential, industrial and commercial purposes, areas for recreation, etc.;
4. farms: non-specialized agriculture, specialized agriculture;
5. forests.

4. Research of immovable cultural property

4.1. The research of buildings

Recently, many older buildings are being reconstructed, adapting them to a new functional purpose. It is necessary to assess the technical condition of the self-supporting structures of such buildings prior to the planned reconstructions. Defects and damages of these structures are identified by studying their condition, development trends are forecasted, and correct calculations of the capacity of the holding force structures are performed, assessing the future load after reconstruction and other possible effects. Condition of the structures operating in aggressive environments, affected by vibrations and impact loads, fire damages, and so on, are often identified. The assessment of the condition of self-supporting structures is necessary for the correction of errors made by designers and builders in the objects under construction past accidents, and only then, the methods, scope, and duration of their repairs are addressed. Thus, the process of maintaining the self-supporting structures in a state of quality throughout use is called the maintenance of the structure. This maintenance consists of a whole set of preventive and other measures that ensure the use and possibility of the building following its purpose and potential. It is essential that the building is used as well and efficiently as possible for its intended purpose. Therefore, a continual maintainance of the quality condition of the building structures, water supply, sewerage, lighting, air conditioning, and other systems that create the necessary environment for people and ongoing technological processes must work without disturbances (timely and high-quality repair or renovation). Regularly exposed to external and internal influences, the structures used in construction, engineering communications, and other technological equipment are worn out because of age, various damages occur_, and finally, they decompose. Therefore, the maintenance of buildings is a continuous, dynamic, and long-term process.

The essential part of the building maintenance is the examination (inspection) of the condition of its structures, where it is examined and assessed visually, together with its instrumental control. Based on the conclusions and recommendations of the assessment, the scope and duration of repairs, the required construction materials, equipment, etc. are estimated (Radziszewska-Zielina*et al.*, 2017)

Designers, builders, and operators working in different conditions solve the same task: to give the building the necessary performance characteristics according to the purpose of the building, and then maintain such characteristics as strength, stability, tightness, thermal resistance, etc.

The characteristics of different purpose buildings are assessed differently. Moreover, different values of characteristics parameters are also typical for building structures made of different materials. For example, the value of the deflections of structures is determined not only by the purpose of the building or its construction but also by the material: reinforced concrete, steel, etc. Relative air humidity is essential from both a technical and hygienic point of view.

The parameters of the characteristics of buildings are scientifically based indicators those of structural elements, environment, etc. The strength of building structures is described by the holding force capacity and the strength of their materials by compression, tension, etc. The tightness of the external walls of a building is characterized by the coefficient of air permeability and thermal insulation – by the factor of heat transfer. The same applies to other indicators of building performance parameters.

Reconstruction or repair projects are based on a task that specifies the most important requirements for the building, including performance parameters, and the approximate cost of construction, as well as design standards and other documents.

The performance parameters of the buildings specified in the design must be implemented during their construction and maintained during use. Two groups of performance parameters describe the suitability for structures:

- **1st parameters are characterizing physical, technical condition, physical durability:** strength, limit deformations, and other indicators. These include probabilistic reliability indicators;
- the **2nd group is the parameters that characterize excellent longevity**: indicators of the compliance of structures with modern requirements according to the volumetric planned structure, engineering equipment, aesthetic, and other features. Not all indicators (such as the appearance of a building) are quantified – then subjective evaluation is used.

A system of measures to assess the technical condition of structures and their structures are inspections and tests (including various tests) (Kutut, 2014).

4.1.1. Process and methods of study of buildings and their structures

The purpose of the study is to determine the actual holding force capacity of building structures, their suitability for further use, and other data required for the preparation of a building reconstruction or repair project. At the same time, it is necessary to look for optimal planned volumetric and structural solutions, ways of strengthening or replacing self-supporting structures, etc. All solutions must be technological, of the lowest costs and the fastest to implement, meet environmental, heritage protection, and other requirements.

Investigations of self-supporting structures and foundations of the constructions are performed, taking into account the requirements of the numerical solution critical state methods. The test structures must meet the requirements of the first and second groups of critical states specified in the applicable design standards.

The normative and design (calculated) values of loads and impacts must be determined based on the actual data and the applicable load and impact standards. Such principles also determine the normative and design characteristics of the foundation soils and building materials of existing self-supporting structures.

Besides, environmental conditions, technological factors, and their impact on building structures and human health are analyzed.

After all the basic researches, an assessment of the technical condition of the building's structures is performed. The evaluation consists of an analysis of the test results, and the final customer agreed on loads and impacts, and the recalculations of the self-supporting structures. Finally, a report on the assessment of the technical condition of the structure is drawn up, which provides conclusions on the state of the self-supporting structures in question and other data.

The examination of buildings and their constructions is carried out by certified engineering service companies, laboratories, or the entitled experts with the necessary means. Specialists of this field must follow the valid normative and technical documents for the reconstruction, repair, research, and use of construction objects.

In preparation for the research, it is necessary to analyze the existing experience related to the particular features of reconstruction, repair, and use of similar construction objects. The basis of the research is a technical task, which specifies the purpose of the reconstruction (or restoration) of the building and the essential requirements for the planned volumetric solution, building structures, loads and impacts, and the general conditions of use after reconstruction or repair. At the same time, it is necessary to choose the construction organization that can perform the planned construction works most efficiently.

The research and subsequent work are coordinated with the Chief Architect's Office and other authority concerned. The research of the buildings is carried out in two stages:

- preliminary or general investigation;
- detailed examination.

In general, the study of building structures consists of the following works: preliminary inspection of structures; technical documentation study; getting acquainted with the peculiarities of the current and future technological process and operation regime; engineering research; detailed value examinations (diagnostics); sampling and testing of construction materials from structures; determination of planned loads and impacts; drawing up and recalculating the calculation scheme of structures and preparation of conclusions (Kutut, 2014).

In individual cases, value tests of buildings or their structures may be carried out. It should be noted that some of the mentioned works can be performed both in the first and second stages of research.

Preliminary or general investigations begin with an inspection of the buildings and their structures, access to the existing technical documentation, and other data that help to form a picture of the object under study.

At this stage, the bars (sections) and individual structures of the building of the emergency conditions are visually identified, and immediate measures are taken to strengthen them temporarily.

The studies of the project technical documentation obtain the following information:

1. about the construction work of the structure and peculiarities of use (for example, previous repairs, reconstruction, etc.);
2. about volumetric scheduled and structural solutions (for instance, acquaintance with construction drawings, designed loads and impacts, layout diagrams of technological equipment, etc.);
3. about the engineering geological and hydrogeological conditions of construction and use of the facility.

In addition to the project technical documentation, other materials are introduced: deeds of release for use, deeds of hidden works, passports of construction materials and structures, certificates, work performance logs, etc.

Some knowledge about the construction and use of the facility can be obtained by interviewing the specialists and other employees of the research building. Preliminary research explains deviations from volumetric planned, structural solutions, including variations of load parameters from the design, etc.

It is necessary to perform measurements of the building and its structures and make necessary drawings when the designed technical documentation is absent. During the analysis it is required to record: deformations of structures (displacements, cracks, etc.) and their deviations from the permissible values; the dimensions and position of the cross-sections of the structures (distances between the axes of the building, etc.); the construction and quality of joints and joints of structural elements, the conditions of their support; the relative strength of construction materials; damage to the integrity of the parts, damping and freezing of their materials; increased thermal conductivity; anti-corrosion protection and other defects and damage.

It is recommended to divide structures into bars (zones) according to the construction material, type, their functional purpose (e.g., roof slabs, beams, columns, walls, foundations, etc.), scale for building structures to facilitate the systematization of value research works and data.

Based on the research data, the technical condition of the buildings and their structures is estimated, and a detailed examination program is prepared.

A detailed examination is one of the diagnostic links of construction objects, the aim of which is to obtain final reliable knowledge to assess the technical condition of structures. It follows that the assessment of the technical situation of the building is the basis for the preparation of a reconstruction or repair project.

During the detailed examination of building structures, it is necessary to obtain: amended technical documentation of the project; measurement drawings showing the actual position of the structures and the dimensions, depositions, displacements, inclinations and other deviations of their units from the requirements of the design or standards; data of the actual values of the physical and mechanical characteristics of the materials (non-destructive and laboratory test methods must be used to the maximum for this purpose); defects and damages of structures, their assemblies and connections have been specified and systematized; data on the operating environment of the structures, the magnitude of static loads and impacts, as well as dynamic loads. After that, a calculation scheme of the investigated self-supporting structures is made, their recalculation and the final assessment of the technical condition is performed.

A detailed examination of all or part of the structures under investigation may be carried out selectively or continuously. The selective examination provides the analysis of individual elements and the continuous – examination of all.

Continuous examination means the inspection of objects with reliability according to purpose factor equals one, in particular, as well as the investigation of objects that technical design documentation no longer exist, their structural defects and infringements, reduce the self- supporting capacity, unequal values of self-supporting characteristics, they are affected by aggressive environments, and so on. If during the continuous examination, it is established that not less than 20% out of more than 20 units of homogeneous construction technical condition of all structures are satisfactory, the remaining structures are allowed to be examined selectively.

The sample of structures to be tested selectively must be determined according to the specific conditions. As a general practice, at least 10% of the same type of construction is selected, but not less than three structures.

At the detailed examination stage, engineering geodesy surveys are performed. They provide the data needed to make accurate drawings of buildings and to specify the geometrical dimensions of self-supporting structures. This makes it possible to determine the displacements of structures and their elements and other deviations from the requirements of the design or norms. Without such data, it is not possible to recalculate structures accurately.

Engineering geological surveys are recommended when there are no: working drawings of the foundations of the reconstructed buildings or other documents about them; engineering geological conditions data of the construction site, and when the building is in a geologically difficult place.

Special engineering hydrogeological and hydrometeorological surveys are carried out when reconstruction is carried out in flooded areas or when they are at risk of flooding, also operating the structures in adverse physical, geological, and hydrometeorological conditions or when a project of the environmental measures needs to be prepared.

It is necessary to assign the examination of the characteristics of structural materials by non-destructive or destructive methods of the constructions with severe conditions (e.g., elevated and high temperatures, low or low temperatures, aggressive environments, etc.).

When examining the condition of building structures exposed to elevated and high temperatures, it is necessary to take into account the heat source, heating method, temperature regime.

If the environment of the structures is aggressive, the degree of its aggressiveness is determined, the condition of the materials of the structures and the influence of the environment are examined. All research data of structures and their constructions are accurately written in specialized journals, formalized by various types of research acts, etc. It is desirable to organize all the data and present them in tables.

4.2. Research works of immovable cultural property

Research of immovable cultural property is a scientific theoretical and practical activity aimed to identify remaining and lost features of the cultural value of immovable cultural objects; to discover in kind and authentic documents the facts confirming the historical development of such objects and documenting all found features of cultural significance, regardless of their value, the degree of survival and replacement (Kutut, 2014).

Scope of data for the research work is determined by the necessary data of the criteria described for the assessment and selection of immovable cultural objects, for the disclosure of the valuable properties of the assessed objects or areas, their parts and elements, proceeding:

- time of creation, construction, installation, formation;
- initial use and subsequent use and duration;
- authorship, foundation;
- historical development of composition and scope;
- artistic style, composition;
- typological, geographical and chronological distribution;
- authenticity of material, construction, method of execution;
- interface with the significant public, cultural and State events, personalities and/or literary or other works of art as well;
- significance for religious communities, communities, and centers;

- connection with the objects of ancient cult or other human activity mentioned in the folklore stories;
- significance for ethnic culture;
- the coherence of the natural and remote environment;
- the importance of creative, unconventional searches of the individual or groups of individuals;
- significance for the cultural landscape;
- the complexity of the culture object according to the primary purpose and/or the subsequent use, historical development of composition and scope.

All the data is based on historical and/or physical researches. Research and design aim to find appropriate technical, planning, construction, and other means to preserve discovered features of authenticity and ways to reveal and highlight the cultural value of immovable cultural property and to integrate such values into the current cultural and economic and other practical activities.

The researches are divided according to the nature of the work performed and the impact of the methods for immovable cultural property. According to the nature of the works, researches are divided into a fixation, historical-artistic development, engineering-technical, supplementary special research:

Fixation. The presence of immovable cultural property is recorded in various ways (diagrams, drawings, sketches, photogrammetric measures, acts, etc.). The fixation is made of: photo fixation, measurements, photogrammetry, topography geodesic works, list of protected elements, technical status report, tree taxation, the act of adjusting the degree of deterioration of the value, the act of adjusting the category of rating, coverage (volume, area) calculations.

Research of historical – artistic development. The characteristics of the cultural value of immovable cultural property are clarified, detailed and supplemented, and destroyed or decimated ones are discovered, features of authenticity and quantity are localized, the historical development of such values, authentic material forming method are revealed, and protected elements and inserts without cultural value are identified. Research on historical-artistic development includes archeology, history and iconography, iconology, art history, architecture, polychromy, historical construction, and decor technologies, urban planning, landscape, stylistics, building evolution, greenery evaluation, chronology, typology.

Engineering-technical research. Technical conditions, materials, and equipment of immovable cultural values are assessed, negative, destructive factors and decay processes are identified, authentic formation technologies are revealed, and recommendations for the preservation of such values are prepared. Engineering-technical research includes: engineering geology, hydrogeology, chemistry, mycology, structures, building materials, engineering networks, moisture, chemical, and biological pollution, physical and geophysical.

Supplementary special research. The research of rare components and elements of immovable cultural property and specific phenomena, or the solution of complex problems of preservation of such objects. Supplementary types of special research are: anthropology, osteology, ethnography, sociology, economics, transport, function layout, dendrology, botany, paleontology, dendrochronology, palynology, paleozoology, petrography, soil, microclimate, hydrology, hydro-technical facilities, and others.

According to the impact of methods on immovable cultural property, researches are divided into non-destructive and destructive:

- **non-destructive research** does not prejudice the immovable cultural property – it is all types of recording works, historical, artistic development, and engineering research using visual, ultrasonic and other non-destructive methods, a study of various archival documents and iconographic materials and immovable cultural property structures (planned, spatial, volumetric, etc.) and evaluative (axiological);
- **destructive researches** have an irreversible effect on immovable cultural property – it is engineering-technical research, during which solid material is destroyed by pits, trenches, boreholes, probes, discoveries, samples, and other means.

The following stages of the research are distinguished according to the scope and composition of the studies:

- **exploratory researches** carried out when it is necessary to specify the scope and content of immovable cultural property, to determine physical condition and the main destruction factors, to localize the survival of authentic material, to identify the types of authentic forms, the essential stages of historical development and inserts of no cultural value. Research of part of the immovable cultural property is also considered to be exploratory;
- **detailed research,** which localizes precisely all surviving features of authenticity and quantity of immovable cultural property, details and concretizes the composition and scope of values, identifies all destroyed or destroyed features of aesthetic significance, all valuable parts, and development, examines all destruction factors and decay processes;
- **additional researches** are carried out when new features of cultural value that have emerged during management need to be investigated and assessed.

The management work programs are detailed based on data of the exploratory research, the project proposal stage of the projects for conservation, restoration, reconstruction, repair with modifications and adaptation works are prepared, the established management regimes can be revised and adjusted as well as. Technical projects for the management work as well as for precursors of accident threat works and repairs without modifications works of the immovable cultural property listed in a separate part can be prepared based on the research data of this stage and work documentation if necessary. Conservation, restoration, recovery, repair with modifications, and adaptation work projects of all stages and territorial planning documents are prepared based on the data of detailed and complex researches. Based on the data of additional research, the projects and conservation, restoration, reconstruction, precursors of the accident, repair, and adaptation works are adjusted (Glemža, 2002).

Research work *must be* carried out:

- when works for the conservation, restoration, and reconstruction of immovable cultural property are planned and projects for such works are prepared;
- when precursors of the accident, repair and adaptation works may damage the authentic material of immovable cultural property. In these cases, researches are carried out at the sites of possible infringements to regulate (or prohibit) the management works referred;
- when new features of the cultural value of immovable cultural property become apparent during conservation, restoration, reconstruction, precursors of the accident, repair, and adaptation works.

Research work *can be* carried out:

- when additional data are necessary to justify the technical and planning decisions for the management of immovable cultural property, and to prepare management work programs;
- when adjusting the cultural value of immovable cultural objects;
- when management work is to be carried out on large, complex, and multistage immovable cultural property with a large number of historical alterations and worthless inclusions.

The types and stages of the required researches are determined for each immovable cultural property separately. The aim of the necessary research work must always be to make it as efficient as possible, such as to enable the required management of immovable cultural property to be identified and substantiated.

The individually required researches are selected by legal and natural individuals who organize and carry out the disclosure of immovable cultural property. The research data must be recorded in the accounting documents of immovable cultural values.

The reviews, certificates, and reports of data obtained from historical and physical researches are stored following the established requirements for the storage of documents.

4.3. Analysis and management of decorative coatings, decorative plaster, plastered, painted surfaces of facades and interiors

All management works, such as research, conservation, restoration, repair of decorative coatings, decorative plaster, plastered, painted surfaces of facades and interiors of cultural heritage objects must be carried out only with the permission of the institutions regulating these activities in the form prescribed by the heritage management regulations.

The management of the decorative coatings, decorative plaster, plastered, painted surfaces of the facades and interiors of cultural heritage objects may be performed only by specialists of the respective qualification of the established qualification category, or by the executors under the supervision of such specialists.

The color and relief decoration of the facades and interiors of cultural heritage objects must be started only in coordination with the regulatory body regulating the preparatory documentation (work program, technical condition assessment act, research conclusions, conservation, restoration methodology) or heritage management project.

Technological processes of conservation and restoration work of color and relief decoration of facades and interiors of cultural heritage objects must comply with the normative and legal requirements regulating the quality of works.

During the treatment of the decorative coatings, decorative plaster, plastered, painted surfaces of the facades and interiors of cultural heritage objects, their protection against mechanical damage and the effects of atmospheric phenomena must be ensured.

The methodology of decorative coatings, decorative plaster, plastered, painted surfaces for facades, and interiors conservation and restoration works are determined based on survived authenticity, conclusions, and recommendations of relevant nature research, archival research, assessment of the physical condition of historical coatings (Glemža, 2002).

Destructive research of facades and interiors or material samples taking must not damage the compositional, polychrome integrity of valuable elements and the expression of individual motifs.

The methodology of management of decorative coatings for facades and interiors, decorative plaster, plastered, painted surfaces must provide for the sequence of works and technological processes, their duration, requirements for atmospheric conditions, materials used for these works and their quantities following regulatory standards.

The materials used for the treatment of facade and interior decorative coatings, decorative plaster, plastered, painted surfaces must not have a destructive effect on the structure of authentic materials (compatibility of materials).

Decorative coatings, decorative plaster, plastered, painted surfaces for facades and interiors must be designed for the structure to meet the requirements of heritage protection and must be maximally resistant to the possible effects of the use and the atmosphere influence.

Decorative elements of facades and interiors formed from decorative coatings, decorative plaster, must be protected by precipitation resistant measures and layers.

Environmental construction products must be selected for the conservation, restoration, restoration, decorative plastering, plastering, and painting of decorative coatings for facades and interiors.

Finishing materials for the facades and interiors of cultural heritage objects must be selected to suit the period and specific type of materials of the historical object if it was possible to determine them. And if the technical condition of the object does not allow the use of historical types of finishing materials, they must be chosen based on technological research recommendations.

Preparation of facades and interiors must meet the essential requirements before using the selected finishing materials and technologies.

When designing and managing decorative coatings, decorative plaster, plastered, painted surfaces for facades and interiors, it is necessary to evaluate the use of the heritage object.

When designing and managing decorative coatings, decorative plaster, plastered, painted surfaces for facades and interiors, it is necessary to evaluate the use of the cultural heritage property, with the research conducted prior.

Preservation of valuable properties must be ensured during the treatment of decorative coatings, decorative plaster, plastered, painted surfaces for facades and interiors.

4.3.1. Research

Surface management projects for cultural heritage structures are prepared after performing historical, artistic, technical, and other necessary researches to determine the current technical condition, nature, degree, and extent of damage of all stratum.

The research aims to determine the technical condition of the decorative coatings, decorative plaster, plastered and painted surfaces of the facades and interiors of the object, the characteristics and attributes of the used materials and the causes of the malfunction of materials and surfaces.

The research begins with an inspection of the object, which must be carried out by specialists who can assess the nature of the violations, the need for further investigations, and the temporary protection of the facility.

For more profound research of the object:

1. the existing documentation is explored, the historical, artistic, technical, and other researches of the object are carried out;
2. photo fixation of objects and measurements of decaying areas are performed;
3. technical condition of the surfaces and materials are described;

4. samples shall be taken for laboratory tests to determine the composition, binders, pigments of decorative coatings and mortars, characteristics of the foundation, its possible contamination, etc.

In case of mechanically weak testing surfaces, it is essential to take as large samples of unbroken plaster or decorative element together with decorative coating and painted layers, carefully lay them on pre-prepared soft but rigid material (wood fiber or other board) pallets, pack in suitable containers and to deliver to the laboratory.

Sampling must not impair the compositional, polychrome integrity of the valuable elements and the expression of individual motives.

Samples for polychrome tests shall be taken from areas more exposed to direct sunlight and atmospheric precipitation with less discoloration.

If the surfaces of decorative coatings or plaster are associated with the base of decaying wood, wood samples must also be taken and analyzed to determine the wood-specific data, degree, and causes of the damage.

The research shall also identify options and methods for cleaning, antiseptic, restoration, conservation, or reconstruction of decorative coatings, decorative plaster, plastered, and painted surfaces using test plots or other methods and make appropriate recommendations. The research data must be reported.

The results of the performed research must be used for the technical documentation of conservation, restoration, or reconstruction of cultural heritage objects and the performance of works.

4.3.2. Management

Conservation. Conservation of decorative coatings, decorative plaster, plastered, painted surfaces of facades and interiors are carried out on the basis of the results of research work and the prepared conservation project.

The purpose of conservation work is to stop the further loss of decorative coatings, decorative plaster, plastered and painted surfaces, to stabilize their physical condition, to strengthen them to last longer. These works first address the causes of heritage loss, followed by consolidation and conservation (Glemža, 2002).

When the decorative coatings or plaster of facades and interiors have lasting value, are polychrome decorated and with time patina, but partial from the base, it is necessary to glue it using the project provided binders in and to stop further decay.

Historical materials and new unique preservation materials, as well as technologies, when it is necessary, are used for conservation. The author of the project determines the need for new unique restoration materials.

The nature of the conservation work and methods used are determined according to preliminary results of the research of facades and interiors and the use of the object.

The surface cleaning must be carried out, if necessary, preserving the time patina, antiseptic coating, and removing plaster damage.

The decorative texture, color layers, and decorative elements of the historical plaster must also be preserved.

Conservation measures must adequately protect the heritage objects from atmospheric precipitation and other destructive effects, be authentic, and look aesthetically pleasing.

Restoration. For a restoration project of a heritage object, it is necessary to have data from value researches and historical art researches.

The aims of restoration are: to establish and preserve, to highlight, and exhibit the authenticity of a cultural heritage property, fragmentally supplement the lost elements of a heritage object and restore the heritage value of the object.

The project for the restoration of decorative coatings, decorative plaster, plastered, and painted surfaces shall include – cleaning of plaster, plastered and painted surfaces (where possible), methods of antiseptic and hydrophobic coating and desalting (if necessary) methods and reinforcement and restoration of damaged plaster and internal management (Kutut, 2014)

Salt-resistant mortars can be used for plastering plinths.

Facade plaster is painted (when necessary) with water vapor and atmospheric carbon dioxide (CO_2) permeable paints, such as lime, silicate, silicone, etc.

Most of the valuable interiors survived in churches, monasteries, town halls, and palaces. Artistically valuable interiors include wall niches, wall openings, ceilings, floors, and plastered or painted stoves and fireplaces. Their restoration requires the results of historical, artistic, polychrome, and architectural researches, with particular emphasis on the remains or traces of the decorative coatings found.

It is possible only to exhibit the revealed authentic fragments, after their preservation and partial restoration and preparation of a draft color solution if the results of the research are few.

The authentic decorative coatings and decorative plaster of the premises are preserved, and the color decision is made according to the most valuable or dominant period of the heritage object.

The historical atmosphere or conditional image of the interior is recovered but not restored if the authentic decorative coatings and plaster have not survived, and the results of the research do not provide consistent data for restoration. Or, at the discretion of the project author, it is proposed to create a moderate modern interior.

The technical condition of the masonry must be taken into account when designing and carrying out interior conservation or restoration works. Damaged masonry must be treated. Walls, columns, and ceilings, with historic plaster, preserving methods must make it possible to protect authentic plaster better. Bounced worthless plaster is replaced with new, using historical materials and technologies.

It is necessary to remove salts (if any) from the lower part of the walls, to perform waterproofing the foundation, if possible, and antiseptic coating the contaminated areas, if necessary.

Interior bounced plaster with valuable decorative coatings is glued to the masonry, reinforced by injection of binders, enhanced as much as possible by chemical agents, carefully cleaned and preserved while preserving the time patina, according to the researches, and, partially restored to match the appearance as authentically as possible, if necessary.

The design and execution of interior reconstruction works must be carried out, taking into account the specifics of the adaptation of the heritage object.

The unveiling of authentic decorative coatings, decorative plaster, plastered and painted surfaces, the supplementation, highlighting, renovation, and display of faded or decayed elements are the most typical restoration works.

The project author can suggest the relevance of revealing the authentic layers.

The addition (fragmentary reconstruction) of obscured or decayed fragments or elements must be based on the results of historical, artistic, technical, and value research, as well as existing historical material – photographs, drawings, drawings, etc. Reconstruction of obscured or decayed fragments may reveal some differences between authentic and restored parts but must maintain the overall aesthetic appearance of the heritage site.

The historical development, architectural or artistic value of a heritage object can be exposed by highlighting and exhibiting decorative coatings or decorative plaster. It is not necessary to seek to restore faded fragments or elements – they can be preserved and presented as authentic examples of the object to be repaired.

Renovation of decorative coatings or decorative plaster for facades and interiors is performed when preservatives are insufficient or do not meet aesthetic and technical requirements.

When the author of the project finds it difficult to decide where to preserve the damaged authenticity and where to restore the surface, based on the results of the research, he must submit his proposals to a specialist council or commission.

Reconstruction. Reconstruction aims to show a significant or former valuable historical image of the facades and interiors of cultural heritage objects (by conducting detailed research and examining the characteristic features and level of technology of the era's technique and style) (Kutut 2014).

It is necessary to use the surviving historical data and the results of the researches of partially survived fragments for the reconstruction of the facade and interior coatings. Reconstruction is carried out following the principles of restoration work.

When there is not enough data for playback, only the historical image of the surface is reconstructed.

When there are only unreliable descriptive data about the former object, modern architectural means are used for the reconstruction, conditionally emphasizing the previous functions of the heritage object, taking into account the old technical and technological traditions of the historical period.

The specifics of the application of the object must be taken into account when designing the reconstruction works of decorative coatings for facades and interiors, decorative plaster, plastered, and painted surfaces.

4.4. Facade and interior surface damage assessment

The forms of damage determine the degree of damage to painted surfaces of facades and interiors to the paint layers and their ratio to the total area: small <5%, medium <25%, high up to 50%:

1. Methods for dirt removal, washing, partial mechanical paint removal, local biocidal treatment, desalination need to be established if the operative life of painted surfaces of facades and interiors is longer than ten years and minor damages are found, such as single spills, single areas of cracked plaster, small amounts of dirt (dust, soot, cobwebs), individual foci of biocorrosion and chemical corrosion.
2. It is necessary to determine the composition of plaster and paint layers, the nature of damage and preservation methods if the operative life of painted surfaces of facades and interiors is longer than ten years and minor damages are found, such as single spills, single areas of cracked plaster, small amounts of dirt (dust, soot, cobwebs), individual foci of biocorrosion and chemical corrosion. It is also necessary to establish methods for the removal of dirt and worthless paint layers, washing, local biocidal treatment, desalination, caulking, gluing layers of plaster, gluing a layer of plaster to the masonry, and filling of losses.
3. It is necessary to determine the composition of plaster and paint layers, the nature of damage and preservation methods if the operative life of painted surfaces of facades and interiors is longer than ten years and minor damages are found, such as single spills, single areas of cracked plaster, small amounts of dirt (dust, soot, cobwebs), individual foci of biocorrosion and chemical corrosion. It is also necessary to establish methods for the removal of dirt and worthless paint layers, washing, local biocidal treatment, desalination, caulking, gluing layers of plaster, gluing a layer of plaster to the masonry, and filling of losses.

When performing polychrome and laboratory tests on painted facades and interiors, it is mandatory to determine:

1. color stratigraphy (chromo-chronology) of paint layers, total area polychrome (multi-coloring) system, the chemical composition of paint layers, pigments and organic binders of primary or exclusive periods, painting technique and structure of plaster layers;
2. destruction of paint layers and plaster layers, nature of disruption, kind of the damage (chemical corrosion – water-soluble salts, and biological corrosion – bacteria, algae, fungi, lichens, mosses, higher plants), causes of destruction and elimination methods;
3. Reconstruction of the color expression of the facade and interior, programming of historical painting technologies, and their use in repainting areas and justification of the application of new painting technologies.

4.4.1. Preparation of surfaces

Temporary protection of the facade and interior. The surface of the facade must be protected from the harmful effects of the atmosphere using sealing, waterproof coverings.

Paving areas, adjoining the plinth part, must be protected from possible damage due to friction, falling objects, dust, dirt, spills, paint leaks or spills. Protective elastic synthetic coatings, wood panel decks, polyethylene film against dust, dirt, and spills must be used for protection against friction.

The scaffolding is attached to the walls for stability, using screw-on metal connections. The protruding parts of the scaffolding are covered with soft synthetic gaskets to protect the plaster and paint from scratches, scratches, punctures.

Removal of dirt, stains and worthless layers. Various methods can be used to clean the paint layers: mechanical manual – by brushing, peeling, scraping, sanding, hot air, cold or hot water jet, compressed air, laser, ultrasound. It is not recommended to use the sandblasting and other abrasive dry or wet methods. Chemical cleaning methods – alkaline and acid-based solutions, pastes are not suitable too.

It is necessary to choose gentle cleaning methods that do not damage historical materials for dirt, stains, and paint layers, that do not have valuable properties, cleanings. If mild methods are ineffective, more aggressive but small-scaled ones can be used:

1. if the surfaces have been painted with lime paint, the paint layers are softened and peeled, washed, and dried;
2. if the surfaces have been painted with emulsion or dispersion paint, the paint layers shall be cleaned mechanically dry or wet, washed, and dried.

The removal of cracked into small pieces and bounced historical plaster or crumbling base materials and intermediate incompatible, destructive materials used in subsequent repairs are done mechanically by hands, shocks, and vibration techniques are forbidden.

When cleaning, removing worthless layers of paint from the facade and interior surfaces, it is necessary to leave one or more stratigraphic-information probes full of historical paintings and exposed in protected and unobtrusive places, neatly designing and preserving them.

It is not recommended to create a new façade look when removing layers (e.g., paint, plaster, and exposing brick masonry surfaces or radically changing the paint color and polychrome paint) that have not been historically confirmed by researches (Glemža, 2002).

Reinforcement and stabilization of the structure of plaster layers. Weak plaster reinforcement can be performed using inorganic, organic, and mixed materials (or their solutions) based on researches and provided in the design. Traditional and synthetic materials or their solutions can be used, based on the principles of material compatibility and reversibility.

Filling of slots in layers must be done with materials analogous to historical ones and using historical techniques and technology based on researches. Traditional, mixed and synthetic materials can be used filling deformation slots in facades and interiors.

Bonding and gluing of bounced, delaminated plaster layers can be done by injection of adhesives based on tests using traditional, mixed, and synthetic materials.

The loss of plaster should be filled with restorative materials based on research, using traditional materials or modern ones, in some cases, following the principles of material compatibility and reversibility. Traditional materials should be used for cultural monuments.

Potholes, fractures, more significant irregularities, planar edges of facades and interiors should be smoothed with restorative mixtures (rubbing), based on researches, using traditional materials and preserving the signs of building aging (time male), reflected in historic architectural surfaces. In other heritage objects, modern materials can be used for restorative mixtures based on the principles of material compatibility and reversibility, in addition to the historical ones.

Salt cleaning and surface biocidal treatment. Desalination of plastered surfaces and valuable paint layers can be done:

- by dry cleaning of the water-soluble crystals and scales from the surface, collecting them in containers and removing them from the construction area;
- by leaching, with swabs of distilled water/absorbent (e.g., cotton wool), dissolving and removing the dissolved salts, and forcibly de-crystallizing them in the swabs;
- by combining dissolved salts into insoluble compounds using certain chemicals;
- by “sacrificial surface” method;
- plastering the facade and interior plaster with a high-porosity plaster, allowing water-soluble salts to accumulate and crystallize in the pores from the lower historical plaster layers.

Desalination methods are selected according to the performed tests.

Biocidal treatment of plastered and painted surfaces shall be carried out with colorless biocidal solutions for plastered surfaces. Biocidal treatment materials and methods shall be selected and investigated following the manufacturer’s recommendations.

Environmental conditions. Facade plaster handling and painting works are allowed to be performed at the ambient temperature of >+5 degrees Celsius. Taking into account that lime surfaces must harden for at least 28 days, it is recommended to start work on the 15th of April and end on the 15th of September. Plastering and painting of the facades are not recommended when the sun directly heats the painting surface, it rains, or the facade is wet or frozen after rain, there is a strong wind. The humidity of the walls is preferably not less than 8%.

During interior management, it is necessary to protect the interior surface from the harmful microclimate in winter, with minimal heating of the premises (>+5 degrees Celsius).

Materials. Materials used for painting and plastering, most not compromise authenticity, must not require authentic surface removal, have a strength less than or equal to the authentic material, are harmless to nature and people, meet aesthetic requirements, and the principles of material compatibility and reversibility. Pigments must be of mineral origin, resistant to alkalis, light, and atmospheric changes.

The use of paints containing harmful constituents (e.g., lead white) is prohibited for ecological reasons, and organic solvents that are hazardous to health must be kept to a minimum.

The grain and color of the decorative plaster must correspond to the authentic. The materials used must have certificates of conformity.

4.4.2. Painting

Various painting technologies are used when painting the facades of cultural heritage objects:

1. traditional historical lime painting technologies and lime or silicate paints of industrial production are used **for cultural monuments**;
2. traditional historical lime painting technologies, lime, or silicate paints of the historical line of the industrial output, modern technologies – acrylic and silicone paints for facades that meet the principles of material compatibility and reversibility are used **forother facades of heritage objects.**

Slaked lime is a key material in the management of the facades of cultural monuments and for the historic lime painting technologies. Plaster surface fasteners – fixatives, primers, paints are produced on-site, according to the project recipes, using slaked lime with the activity of > 67% (lime water, lime – potassium aluminum alum primer, lime paints), pigments of mineral origin, resistant to alkali, light, atmospheric changes.

Paints and primers of the same company are used when painting facades with industrially produced lime or silicate paints – painted according to the manufacturer's technology.

Modern painting technologies (synthetic paints of industrial production) are used for painting, colors, and primers of the same brand, and complying with the principles of compatibility and reversibility are used and painted according to the manufacturer's technology.

The painting of plastered surfaces of facades should be done only after repairing the structures of the building (when repairing the wall and floor structures, dried masonry, stabilized plastered surfaces, filled with losses, desalination of plastered surfaces and biocidal treatment). Painting is possible only after 28 days after the completion of plaster maintenance work when the substrate is dry, clean, and secure.

Using traditional historical technologies – the cleaned plaster surface must be washed with drinking water, reinforced twice with lime water with the 8 to 12 hours period between operations. Two coats of potassium aluminum alum primer must be applied, keeping the 8 to 12 hours period between primers and two coats of lime paint refined with flax oil are used following the 8 to 12 hours periods between stains. 10% of the binder content of the marble flour is added to the first coat for better coating if there are many different fillings in the facade plaster.

When painting with the historical production line of lime paint, the cleaned plaster surface is washed, dried, moistened with drinking water, fixed with fixatives recommended by the same company, two coats of primer, and two coats of lime modified paint are applied according to the manufacturer's instructions.

Plastered surfaces are washed with drinking water, dried, primed, and painted with paints made based on synthetic binders, diluted with water using modern technologies of industrial production for painting. Fixing, priming, painting materials must meet the requirements for compatibility and reversibility of materials, according to the manufacturer's technology and specified in the technical documentation.

Painting parts of the heterogeneous plinth of the facade can be carried out using industrial lime modified paints according to the manufacturer's technology or paints based on industrial production synthetic resins also according to the manufacturer's technology.

In interiors, it is recommended to perform plaster handling, and painting works at ambient temperature not less than + 8°C and not more than + 25°C, and wall humidity not less than 8% and relative humidity, not more than 70%. The temperature is measured at the height of 0.5 m from the floor. The temperature difference between the individual points in the room must not exceed 10°C.

Materials.

1. It is recommended to use painting materials similar to historical ones, which comply with the principles of compatibility and reversibility, do not damage the original, do not require removal of the original, have compressive strength less than or equal to the original, form a stable coating and are harmless to nature and people. Pigments must be of mineral origin, resistant to alkalis, light, and atmospheric changes.
2. The use of paints containing harmful constituents is prohibited (e.g., lead white), and organic solvents hazardous to health are reduced to the lower limit of the permitted levels. The paints must have certificates of conformity.
3. Coatings of the paints must be permeable to water vapor. If the paint is used to paint freshly made plaster, the paint coatings must also be conducive to carbon dioxide (CO_2) to ensure that it hardens.
4. Paint preparation.

Lime paints are mainly used to paint the "monastery palter" plastered surfaces of churches and monasteries, using historical technologies. The primary material is slaked lime. The used mineral pigments must be resistant to alkalis, light, and microclimate changes. Plaster surface fasteners – fixatives, primers, paints are produced on-site according to the recipes provided in the project, using hydrated lime with an activity of > 67% (lime water, potassium aluminum alum primer, lime paints refined with linseed oil). Paints and primers are prepared at the workplace.

The walls, ceilings, and domes of churches, palaces, manors are usually painted with adhesive and chalk paint. Binder is an adhesive of animal or plant origin. Pigments must light, microclimate changes (humidity) resistant. Plaster surface fasteners – affixation, putties, primers, paints are produced on-site, according to the recipes provided in the project. Restorers and painters prepare paints and primers.

Oil paints are mainly used for decorative painting of churches, palaces, manor walls, ceilings, domes. Binders are the drying oils. The paint is diluted with drying flax oil or alkyd oil and turpentine as provided for in the project. Certified restorers prepare paints and primers according to the color intensity of the polychrome painting project. Artists can use specialized industrial oil paints of appropriate colors.

Emulsion paint is most often used for decorative painting of walls, ceilings, and domes of churches, monasteries, palaces, manors. Plaster surface fasteners, putties, primers, paints are produced on-site, according to the recipes as provided for in the project. Restorers and painters prepare paints and primers according to the color intensity, gloss, and haze of the polychrome painting project. Artists can use specialized industrially produced ready-made natural emulsion paints (tempera) of appropriate colors.

1. Painting of plastered surfaces of interiors shall be performed after the structures of the building are repaired and plaster coated surfaces prepared (wall and ceiling constructions repaired, masonry dried, plastered surfaces stabilized, plastered surfaces biocidal treated, salts dust, grease or bitumen stains removed, plastered surfaces are reliable, clean, dry, smoothed according to the preserved historical surfaces). Painting can be done after 28 days of the plaster has been finished. Historical painting technologies are used when repainting historic interiors if the project aims to preserve the specific historical character of the interiors, as well as knowledge of construction crafts.
2. Historical oil and emulsion painting technologies can be replaced with modern, water-based dispersion paints to prolong the service life of the interior and more straightforward maintenance of painted surfaces, the lower parts of the walls, and lower architectural, the artistic value in the premises.
3. It is obligatory to perform partial or continuous, repeated, reinforcement-priming, surface leveling-plastering, sanding, washing, priming, and painting operations on manually plastered surfaces when painting or repainting plastered surfaces arranged in interiors. Test painted surfaces shall conform to historical colors, gloss, haze finish, and texture.
4. For painting with lime paint, the surface of the plaster is washed with drinking water, reinforced twice with lime water with the 8 hours between operations, then potassium aluminum alum soil layers are applied twice (every 8 hours) and lime

paint refined with flax oil is applied twice(every 8 hours). If there are many different fillings in the plaster, then 10 – 20% of marble flour (based on the amount of binder)is added to the first layer for better coating.

5. For painting with water-based adhesive paints, partial or continuous fixing of the plaster surface is performed – priming, puttying, sanding, cleaning, washing, painting. The test painted surfaces must meet the historical ones in terms of color, haze finish, and texture. A bio-resistant synthetic binder can replace the biocorrosion-resistant binder (e.g., skin adhesives are replaced by KMC adhesives).
6. For painting with oil paints, it is obligatory to perform partial or continuous, repeated, reinforcement – priming, surface smoothing – puttying, sanding, cleaning, priming, and painting operations on manually plastered surfaces. The test painted surfaces shall meet the historical ones in terms of color, gloss, matte finish, and texture.
7. For painting with emulsion paints, partial or continuous fixing of the plaster surface is performed – priming, puttying, sanding, cleaning, washing, priming, painting. The test painted surfaces shall meet the historical ones in terms of color, gloss, matte finish, and texture.
8. Plastered surfaces are washed with drinking water, fixed with deep primers, plastered, primed and painted with paints based on synthetic binders (dispersions), diluted with water using modern painting materials, and technologies of industrial production. Materials used for fixing, priming, and painting meet the requirements of material compatibility and reversibility, using single-brand materials and according to the manufacturer's technology.
9. The modified historical lime paints or other paints may be used for painting the lower parts of walls according to the manufacturer's technology.

4.4.3. Requirements for painted surfaces

The quality of painted surfaces is assessed only when the water-based paints are completely dry, and a strong film has formed on the surface of oil, emulsion, or dispersion paints.

Lime paint painted surfaces must be smooth, free of stains, streaks, leaks, splashes, no visible traces of brushes, no luminous stains, no fading of limescale-resistant pigments, fading of light-resistant pigments, discoloration of the paint layer. In the case of polychrome painting, the deviation of the edge of the strip or color shall not exceed 1 mm per 1 m. The paint layers must adhere firmly and evenly to the surface to be coated.

Water-based adhesive chalk paint painted surfaces must be perfectly smooth, free of stains, stretch marks, leaks, splashes, brushed hair, and not greasy.

Lime-modified paint painted plastered surfaces must be smooth, free of stains, stretch marks, leaks, splashes, no visible traces of brushes. When applying decorative painting, the deviation of the strip or color edge shall not exceed 1 mm per 1 m, without luminous stains, without fading of non-lime-resistant pigments, without fading of light-resistant pigments, without abrasion of the paint layer, mottle fading, cracks. The deviation of the edge of the strip or color shall not exceed 1 mm per 1 m in the case of polychrome painting. The paint layers must adhere firmly and evenly to the surface to be coated.

Oil paint painted surfaces must have the same shade, glossy, or haze texture. Undercoating, stains, stickiness, wrinkles, leaks, pieces of film, visible grains of paint, lime explosions, scattering irregularities, or brush streaks are impermissible, curvatures in contact with two colors are unacceptable, stripes or colored edges deviations must not exceed 1mm per 1m. The paint layers must adhere firmly and evenly to the surface to be coated.

New technology dispersion water-based paints painted plastered surfaces must be smooth, without stains, brush hairs, translucent underlays, stickiness, wrinkles, leaks, pieces of film, visible paint grains, brush strokes, run-offs, lime explosions. The paint layers must adhere firmly and evenly to the surface to be coated.

Qualification requirements for restorers. Plastered surfaces of facades and interiors in cultural heritage objects may be painted only by certified specialists. They know the general features of historical plastering and decorating technologies, and their interaction, properties of constituent materials, knowledge of conservation requirements for restoration materials, material compatibility, and process reversibility.

They must also be able to assess the physical condition of plastered and painted surfaces, understand the interaction between paint layers and plaster layers, the nature of the damage, be able to analyze defects, and use research to predict the sequence of conservation-restoration work.

They must also be able to clean plastered and painted surfaces (remove the dirt, subsequent, worthless layers of paint), recognize and remove incompatible plaster fillings (cement) for following repairs, glue the laminated plaster layers, reinforce plaster structure, biocide restoration, loss recovery damaged surfaces, desalinate damaged areas of water-soluble salts, prepare surfaces for painting, perform multiple monochrome (partially polychrome) painting operations and design and conservation of stratigraphic-information probe for historical painting (Kutut 2014).

5. Immovable cultural property maintenance and management

5.1. Modes of use of immovable cultural property

The purpose of the application of the use modes of immovable cultural property is to define the schemes of use and to link them with the cultural value, and authenticity of the immovable cultural property, and the types of cultural values.

The mode of use is a set of restrictions and conditions of usage for immovable cultural property established by the State, which correspond to the cultural value and authenticity of such objects and enables exhibiting. The modes of use are determined by the protection regulation of immovable cultural values. The permission and scope of use and the required exposure conditions are determined based on the modes of usage.

The modes of use of immovable cultural property are:

- reservation,
- limited use,
- universal.

Modes of use are directly intended to protect one of the features of the authenticity of immovable cultural property – the function. For which they were formed or changed in the course of history. The element of cultural value – quantity – is also protected when the uses and scope of the use of immovable cultural property are determined by the modes of use in a way that there would be no need to change the scope and composition of these properties substantially. All features of cultural value are detected through the identification and evaluation of objects that may have cultural value and social significance, and through the accounting of immovable cultural property. Attributes of cultural value can be supplemented and clarified by researching the immovable cultural property. Value features are recorded in the accounting documents of immovable cultural property. All modes of use are also intended to create conditions for the proper display of immovable cultural property – their visit, inspection and, in coordination with the owners of such values, photography, filming, etc. Exhibition requirements are established by drawing up regulations for the protection of immovable cultural property. Obligations imposed due to exhibition requirements in the territories of immovable cultural property shall be registered as land easements following the applicable procedure. Modes of use limit the uses and scope of usage of immovable cultural property (Kutut, 2014).

The purpose of the use is the area (nature) of the use of the immovable cultural property for today's needs. Depending on the established mode of use, the immovable cultural property may be used:

- for cultural and scientific cognition purposes: researches and observation, cultural education and training, memorial purposes, expositions and museums, cognitive recreation, cultural tourism, etc.,
- for economic and other activities: economic – commercial, industrial, residential – household, social, service, sacral, recreational, etc.

The conservative purpose of land use is established for the territories where the immovable cultural property is used for cultural and scientific purposes. If the immovable cultural property is used for economic and other activities, a different primary purpose of land use may be established for the territories. The primary intended use of land for the immovable cultural property is determined and changed following the procedures in force based on the use regimes established in the regulations for the protection of immovable cultural property.

The use of immovable cultural property for economic and other activities must comply with the following principles:

- purpose, scope and peculiarities of the use must not lead to changing the scope and composition of such values fundamentally and to the authenticity damage,
- intended use must not substantially differ from the authentic function or the functional type of such values.

The use of the immovable cultural property is prohibited:

- for the storage and production of explosives and flammable materials,
- for the storage and production of substances that pollute such property and areas, water and air pools,
- o form landfills and other waste storage sites,
- for the storage and production of substances that emit harmful fumes and gases and other emissions,
- to create the quarries, mines and other mining objects,
- for the manufacture of machine tools, equipment, and other mechanical motors which have a dynamic and vibratory effect on the structures of valuables, which may cause accidents on these structures,
- for the production, laboratories and storage facilities associated with adverse temperature and humidity regimes and the use and storage of chemically active substances.

The scope of use is the intensity of use of the immovable cultural property for today's needs. It is expressed in various technical indicators (depending on the purpose of use and type of property):

- development,
- hard plating,
- afforestation, water areas, and density,
- total, residential, working or industrial area of constructions,
- number of apartments,
- number of workplaces,
- capacity or capacity (number of visitors, hall areas, number of books, etc.),
- production capability (units of production).

The types of immovable cultural property are:

- archeological,
- cultural sites,
- memorial sites,
- construction complexes and ensembles,
- constructions,
- construction dependencies.

The owners of immovable cultural property may be eligible for tax relief for losses incurred due to operating restrictions and established easements depending on the established modes of use.

5.1.1. Reserve mode

Reserve mode means restrictions and conditions of use that protect all remaining features of authenticity (material, shape, technique, location, timestamps) and quantity (volume, composition) from the adverse effects of economic and other practical use and allow for a different display.

Commercial use of the immovable cultural property is prohibited under the reserve mode, except for activities related to the maintenance, management, and display of such property. The reserve mode is not intended to preserve or restore authentic functions. The reserve mode allows:

- to use the immovable cultural property only for cultural and scientific cognition,
- to use the immovable cultural property only to the extent that it does not change the scope and composition of such property does not damage the features of authenticity,
- to carry out works related to the realization of the purpose and display of the use of immovable cultural property, and works permitted following the established management modes and maintenance conditions.

The reserve mode applies to the immovable cultural property and parts that retain most of the features of authenticity, have no or almost no inclusions of cultural value, and which have irreversibly lost their authentic function. The reserve mode also applies to those that are unused and cannot be used for economic and other practical activities due to their fragmented volume and composition. The reserve mode also applies to those immovable cultural properties that have been created for non-economic or other efficient use. In exceptional cases, the reserve mode may be applied, not withstanding the requirements, as mentioned earlier, to immovable cultural property, which has a unique social significance and symbolizes the most important events in the history of the nation and the state (Kutut, 2014).

The reserve mode is mostly applied in objects of State significance, and immovable cultural properties located in cultural reserves. The reserve mode must apply to:

- archaeological objects and their parts thereof not used for economic activities, regardless of the nature and extent of their physical damage,
- idle memorial sites and their parts regardless of the nature and extent of their physical damage,
- structures of any level of physical damage – works of monumental art,
- dependencies of the structures of any level of physical damage that they are not of the primary practical use objects,
- structures, structure complexes and ensembles and areas of cultural sites, applying the exceptional reserve mode.

The reserve mode can apply to:

- archaeological property and their parts that are used for economic activities,
- memorial sites and their parts in use,
- the remains of structures and structure complexes and ensembles that are unused and cannot be used for economic activities due to their fragmented scope and composition,
- the essential areas of structure ensembles and complexes and the cultural areas. The most important are those areas which show the original form of such values and the vital stages of historical development,
- areas of structure ensembles and complexes and cultural sites that have been created for non-economic or other practical uses (parks, cemeteries, etc.).

The primary purpose of land use of areas of immovable cultural property for which a reserve mode has been established is conservative. The immovable cultural property for which a reserve use mode is defined is subject to preservation and preservation-restoration management modes.

5.1.2. Restricted use mode

Restricted use mode means restrictions and conditions of use that regulate the impact of economic and other practical use on all remaining features of authenticity and quantity and seek to reduce the effect of the use of non-valuable inclusions (Kutut, 2014).

Under the restricted use mode, the uses and scope of use are regulated to ensure the least possible adverse effect on today's needs or that the use would be the same or close to the authentic function and scope and would create appropriate exposure conditions.

Restricted use mode is intended to preserve or restore an authentic or close function if real conditions allow. The following designated use of the immovable cultural property is permitted under the restricted use regime:

- all uses that are the same or close to the authentic function,
- purposes of economic and other activities that are not related to intensive production and do not require significant changes in value: cultural, educational and scientific institutions, administrative, commercial, residential – domestic, recreational, tourism, representational, sacral, etc.

The following uses of immovable cultural property are permitted under the restricted use mode:

- the scope of the authentic function or close to it,
- extent that does not necessitate a substantial change in the scope and composition or authenticity of the values.

The restricted use mode applies to the immovable cultural property and parts that have retained most of the features of authenticity with non-valuable inclusions and which can be used for today's needs without damaging their cultural value (i.e., without altering the scope and composition of such property), or for which it is possible to preserve or restore their authentic or close function. The use of all non-valuable inclusions that substantially alter the characteristics of authenticity and quantity must be reduced and changed following the requirements of the established use mode.

The uses of non-valuable inclusions that do not affect the cultural value are changed following the requirements of the established use mode and by adapting such inclusions to the needs of the use of the immovable cultural property. If the applications of such inclusions comply with the set use mode, they shall be retained. The use of non-valuable inclusions that do not affect the cultural value is not changed or can be reduced.

The restricted use mode usually applies to the immovable cultural property declared as cultural monuments and to immovable cultural property located in cultural and complex reserves.

Restricted use mode shall apply to:

- archeological sites and their parts, memorial sites and their parts, remains of structures and structure complexes and ensembles, essential areas of structures and complexes and cultural sites, as well as other immovable cultural property, if no reserve mode has been established for them,
- for all structure dependents.

The restricted use mode may apply to structures, structure complexes, and ensembles, as well as cultural sites and their areas, that are slightly physically damaged and have few non-valuable inclusions that do not affect the cultural value of such properties and may be used for the purposes permitted in this mode under their extent and composition.

The primary captive use of land of the territories of immovable cultural property of limited or universal modes may be for agriculture, forestry, and others. In all these cases, the use of land in areas of such values is governed by restrictions for the protection of immovable cultural property and special conditions for the use of land and forest. Generally, the immovable cultural property of restricted or universal use modes is subject to preservation-restoration or restoration management modes.

5.1.3. Universal mode

Universal mode means partial restrictions and conditions of use designed to facilitate a wide range of uses and to reduce the negative impact of use on the remaining features of authenticity and quantity (Kutut, 2014).

The universal mode does not restrict the use of the immovable cultural property. Various activities are permitted at such properties by regulating the scope of use. The universal mode seeks to reconcile use for today's needs with the preservation and reconstruction of cultural value. Authentic or close to the functions are permitted that do not cause the need to fundamentally change the scope and composition or features of authenticity, the scope of use of the immovable cultural property. The universal mode applies to the immovable cultural values that have retained some of the features of authenticity and quantity, forming the entirety amid the fragmentary with a significant proportion of non-valuable inclusions of different degrees of activity. Such properties may have lost their authentic function, and it is not objective to restore or preserve them if they have survived. All non-valuable inclusions that substantially alter the characteristics of authenticity and quantity must be reduced, and their uses changed according to the requirements of the established use regime. The scope of use of non-valuable inclusions that do not affect the cultural value is not changed but can be reduced.

The universal mode applies to:

- structures, structure complexes and ensembles and cultural sites and areas and other immovable cultural property, provided that they have not been subject to a restricted use mode,
- all non-restricted immovable cultural property.

The universal mode cannot be applied to archeological sites, memorial sites and structures.

5.1.4. Application procedures for modes of immovable cultural property use

The modes of use of immovable cultural property are established by the State institutions responsible for the protection and management of the property. Modes of use are imposed for the immovable cultural property such as:

- large, complex and multi-stage properties of all types, characterized by historical change of functions and typological multifunctionality,
- properties of conflict situations that arise due to their mismatch between their cultural value and their modern use,
- cultural sites for which draft protection regulations have to be prepared following the established procedure or for which such drafts have been prepared.

Certified management specialists establish the modes of use of the immovable cultural property for the protection of immovable cultural property with a specialization in cultural heritage protection and cultural heritage management. The certified management specialists use data of the immovable cultural heritage accounting documents to establish the mode of use of the property having regard to the conditions of use referred to in the papers of the property rights. Data of previously carried out researches, data of spatial planning documents, projects, research papers, and other documentary information material must also be used.

In complex and conflicting cases, modes of use may be determined based on:

- written conclusions and proposals for modes of use of experts specializing in the property for which the modes of use are established,
- written conclusions and recommendations regarding the modes of use of the commissions formed following the established procedure,
- approved planning documents (if any).

The modes for the use of immovable cultural property are determined by concluding the regulations for property protection. The established modes and exposure requirements are specified in the conditions of use section of the protection regulations. Protection regulations are drawn up following established rules.

According to the established modes of use of immovable cultural properties, there must be:

- the primary targeted purpose of land use of areas of such cultural property determined and changed,
- special conditions and easements for the use of land and forest in the areas of such cultural value established,
- the terms for the use of buildings, structures, and apartments that are of such cultural values or their parts, or which are located in the territories of such cultural values, determined,
- the nature and scope of the adaptation work determined.

The modes of use of the immovable cultural property must be specified following the legislation in force:

- in special (plans of reserves and conservations, planning schemes of national and regional parks, projects for the protection of protected landscape objects, natural and immovable cultural monuments) and all detailed planning documents of protected areas and other areas containing immovable cultural properties,
- in the land use restriction part of the data directory of the state land (with real estate elements) cadaster and city (district) land registry,
- in all property deeds,
- in the conditions precedent of auctions, leases, and other transactions,
- in terms of design (monument management) of works for the management of the immovable cultural property.

In cases where protected territories are established for the preservation of immovable cultural properties, the planning schemes of these territories are prepared based on the established modes of use of such cultural values. The established modes of use are given priority when using immovable cultural properties located in protected territories. Such cultural values may not be subject to different conditions and restrictions of use if they conflict with the modes of use.

Depending on the authenticity and quantity of the parts and elements containing the immovable cultural property, the number of non-valuable inclusions and the degree of their activity, and taking into account the current ownership structure, such property can be zoned according to modes of use.

Zoning according to the modes of use:

- different modes of use for individual parts or areas of such cultural values can be determined,
- another purpose of use can be specified for non-valuable inclusions than for the cultural values,
- different modes of use can be determined for individual parts of cultural values than for the non-valuable inclusions,
- different scope of use can be determined for individual parts of cultural values, and non-valuable inclusions as well.

All types of large, complex and multi-stage cultural values with historical functional changes and typological multifunctionality, or cultural sites for which projects of protection regulations have to be prepared or have been prepared following established procedures can be zoned according to the modes of use.

Usually, zoning according to the modes of use is carried out:

- in the cultural areas: old towns, historic urban and township areas, ethnographic villages,
- in structure complexes and ensembles: manors and folwarks and other homesteads, monasteries, palace complexes and ensembles, factories and other complexes,
- in archeological values: in the cultural strata of the historical zones of the cities, in the hillforts of industrial use and the ancient settlements and production places, and their parts.

Memorial sites in use, as well as large, complex, and multi-stage buildings with a multiple ownership structure, can be zoned depending on the modes of use.

In all cases where the immovable cultural property is zoned according to the modes of use, the conditions of use of their protection regulations must specify all particular components or areas of the property and the non-valuable inclusions and the specific modes of use assigned to them.

The zoning of cultural sites, for which protection regulations' projects must be prepared following the established procedure, shall be indicated in the scheme of the visible part of modes of use of such projects. If the zoning of immovable cultural property with the established protected areas is created, it shall be specified in the functional zoning scheme of these areas according to the modes of use.

The modes of use enter into force on the sheet day of the regulations on the protection of immovable cultural property. They are valid until the supplementation and revision of these regulations, which are carried out following the established procedure (Department of Cultural Heritage, 2020).

The reasons for changing the modes of use and zoning according to the modes of use can only be a change in the characteristics of the authenticity and quantity of the immovable cultural property, i.e.:

- clarification of such features or identification of new features through researches,
- partial or complete loss of such features due to various causes of extinction.

A change in ownership or purpose may not be a reason for changing the modes of use.

In individual cases, changes in ownership structure may lead to adjustments in the zoning according to the modes of use, which does not necessitate a change in the characteristics of authenticity and quantity.

The modes of use of immovable cultural property are changed by the State institutions responsible for the protection and management of property, which has concluded regulations for the protection of such property based on:

- submitted research reports, specifying or identifying new features of authenticity and quantity. Such reports shall be provided by the experts who carried out the researches following the established procedures for project coordination and authorization,
- acts of damage to immovable cultural property in the event of a partial or total loss of authenticity and quantity due to various causes of extinction. Such actions are submitted by the control services of the state institutions responsible for the protection and management of valuables.

The amended modes of use of immovable cultural property enter into force after supplementing and clarifying the regulations for the protection of such property, specifying changes in the conditions of special and detailed planning, state land cadastre, all ownership documents, design of real estate management works, auctions, lease tenders, and other transactions.

5.1.5. Implementation monitoring for methods of immovable cultural property use

The established modes of use of the specific immovable cultural property must comply with the general requirements set for them. The owners and managers of immovable cultural property or their parts (if such ownership is fragmented into separate property units) can check whether the established modes of use meet the requirements before signing protection regulations. If the established modes of use do not comply with the general requirements or are in dispute, the owners and managers of the valuables and their parts have the right to appeal against such modes following the established procedures. The committee resolves discussions regarding the modes of use in the presence of the owner or manager of the immovable cultural property or its part who does not agree with the secure mode, the management specialist who established the mode of use, a person authorized by a state institution and certified experts. The committee's written decision shall be annexed to the protection regulation (Department of Cultural Heritage, 2020).

The implementation of the established modes of use of the immovable cultural property is controlled by the expertise and control authorities and territorial subdivisions of the State institutions responsible for the protection and management of the valuables. They:

- coordinate the relevant documents following the established procedure,
- register the transactions for the immovable cultural property,
- provide the conditions for the use of such values and their territories to the managers of the state land cadastre,

- oversee the management, use, and disposal of immovable cultural property,
- inspect the data in the State land cadastre for land-use restrictions in the territories of immovable cultural properties,
- control auctions, leases and other transactions for the sale of immovable cultural property,
- carry out other activities provided by the regulations of authorities.

Municipal monument protection services or officials, when performing the actions provided by their regulations, must not only control the implementation of the established modes, but must also notify the territorial unit responsible for the protection and management of valuables of violations of the established modes of use.

In all cases, where the immovable cultural property is divided into separate property subjects, a general regulation for the protection of such property must be prepared following the established procedure, which determines the mode of use for the entire immovable cultural property. When separate protection regulations are drawn up for each part of the property, the mode of use of that part shall correspond to the mode established in the general protection regulation of all immovable cultural property according to the managed part of such value. When renting immovable cultural property or their parts, the established modes of use and conditions of the display cannot be changed. These modes must be specified in the leases.

When documents of the applicable legislations provided specify conditions for the use of immovable cultural property other than the mode of use established in the regulations for the protection of such property, such documents cannot be combined or registered by public authorities responsible for the protection and management of the property. In all cases, the owners and managers of such property are fined following the established procedure if non-compliance with the set mode of use has caused damage to immovable cultural property. Following the procedures in force, they must also compensate for the damage made, and restore the damaged part specified by the inspection authorities. If no damage has been caused due to violations of the use, but the exhibiting of such values was restricted, the owners and managers of the values are warned or fined following the established procedure. In all cases where the established modes of use are not complied with, the owners are not entitled to the tax benefits provided for losses due to operating restrictions and established easements.

5.2. Modes of immovable cultural property management

The purpose of applying the modes for the management of the immovable cultural property is to define the management modes and link them to the cultural value and authenticity of immovable cultural property, the types of property, and the extent to which the property is preserved.

The management mode is a set of works for the management of the immovable cultural property established by the State, which corresponds to the cultural value and authenticity of such property. Management modes are determined by a regulation on the protection of the immovable cultural property. Based on the management modes, the permitted types of handling work are determined (Kutut, 2014).

The management modes of the immovable cultural property are:

- preservation,
- preservation- reconstructrion,
- restoration,
- restoration-reproduction.

All management modes are designed to preserve the following features of the cultural value of the immovable cultural property:

- authenticity,
- quantity.

All features of cultural value are identified through the identification and evaluation of objects that may have cultural value and public significance, and through the accounting of immovable cultural property. Feature of the value are recorded in the accounting documents of immovable cultural property and can be supplemented and clarified by researching immovable cultural values.

Authenticity is a quality that defines the fact of the formation of the immovable cultural value in the first place, with all valuable historical changes and additions and the ways they were included in the context of the whole.

Valuable changes and additions are considered to be with the natural features of cultural value or, together with the elements of the previous stages, form a package of such features.

Authenticity features are:

- **material** – artificial (construction, decoration, engineering equipment, decor, etc.) materials, products, articles, and constructions; natural (rocks, greenery, water, etc.) materials, objects and structures and anthropologized natural structures (cultural layers, burials, etc.) that form the immovable cultural values,
- **form** – the planned, spatial and volumetric structures of immovable cultural values, facades, interiors, relief, paving and silhouettes, constructive and technological structures, the stratigraphy of cultural layers, compositional means and properties that form the shape of the immovable cultural values,
- **technique** – is the method of shaping the immovable cultural values (construction, installation, production, layout, self-formation, etc.) and the technology of production of materials from which these values are formed,
- **location** – a part of the surface or other object occupied by the immovable cultural property,

- **function** – the purpose the immovable cultural property was formed or later changed. Functions are protected by modes of use of immovable cultural property following established rules,
- **signs of the time** – are signs of the long-term impact of the natural and human environment on immovable cultural values,
- **original idea** – worldview, lifestyle, traditions and customs, motives, ideas, or projects based on which real cultural values are formed. The original idea is protected by applying the reconstruction of the immovable cultural values following the established rules.

Quantity is the real quantity of the survived totality of the object of the original formation of the immovable cultural value with all historical changes and additions.

The indicators of quantity are:

- the scope is the amount of immovable cultural property measured in individual supplementary units,
- the content is the relating parts and elements taken as a whole, creating the immovable cultural value.

A legal object of protection is an object of cultural value and social significance, the protection of which is legalized by law. The legal objects of protection for which processing regimes are established are:

- immovable cultural values,
- immovable cultural values declared as cultural monuments.
- The types of immovable cultural property are:
- archeological,
- cultural sites,
- memorial sites,
- structural complexes and ensembles,
- structures,
- structure dependencies.

The extent of preservation is the specific material and structural parts and elements that conclude the immovable cultural property and have the characteristics of cultural value, and their quantity in the property. The preservation of these parts and elements determines the survival of the value of such properties.

The extent of protection is determined by drawing the regulation for the protection of immovable cultural property based on accounting documents and research data.

The extent of protection can be:

- **overall** – when all the material and structural parts and elements creating the immovable cultural value are preserved,
- **component** – when separate material and/or structural parts with cultural features that constitute the immovable cultural value are preserved,

- **fragmented** – when original material and/or structural elements with cultural characteristics of the immovable cultural value are preserved.

5.2.1. Preservation mode

Preservation mode is a set of certain management operations that stop (eliminate, regulate) the effects of external and internal destructive factors and establish all remaining features – material, form, technique, location, time-signs, and quantity – scope, composition – characteristics of authenticity in the current situation. The preservation mode must guarantee protection against further excavation and possible alterations and ensure the extension of the existing state of existence and the possibility of exposure (Kutut, 2014).

The preservation mode does not highlight or disclose lost cultural value, nor does it restore damaged or destroyed components, elements, or fragments thereof.

Only the following management operations are performed under the preservation mode:

- technical researches – to assess the functional condition, to determine the negative factors of decomposition and d processes,
- all types of preservation work,
- precursors of accident exclusionworks that do not damage or minimally damage the features of authenticity and quantity.

Research, preservation, precursor of accident exclusion, and adaptation works are carried out following the established rules.

Particular precursor of accident exclusion and adaptation work may result in local damage of the authentic material at the locations of technical and exposure facilities.

In such cases, it is mandatory:

- to minimize the amount of material destroyed,
- to install such facilities in the least essential locations possible (if engineering solutions allow),
- to use of reliable and durable modern materials that do not adversely affect the authentic material and are different,
- to apply the principle of reversibility, i.e., to make it possible to obtain technical measures and to restore the status quo in those places, if necessary,
- to identify vulnerabilities and, if the value is unknown, conduct research.

The preservation mode applies only to those integral immovable cultural property, parts, or fragments thereof, which retain most of the features of authenticity and have no or almost no non-valuable inclusions, regardless of the remaining scope and composition and the multi-stage development of such property.

The preservation mode most often applies to the objects of State importance, cultural monuments, and immovable cultural property located in cultural reserves (Glemža, 2002).

The preservation mode must apply:

- to physically intact archaeological values and their parts,
- to physically intact and discarded memorial sites and their parts,
- to physically intact and slightly damaged structural dependencies.

The preservation mode, as an initial stage of management work, may be applied:

- to physically damaged archaeological values and their parts where the factors of destruction no longer function or natural exogenous decay processes take place,
- to memorial sites and their parts that are slightly physically damaged and no longer in use,
- to physically intact and slightly damaged structures and ensembles of structures and their parts,
- to the essential areas of building complexes and cultural sites. The most important are those areas that show the original form of such values and the most important stages of historical development or are most characteristic of such values.

5.2.2. Preservation-restoration mode

The preservation-restoration mode is a set of particular management works that preserve all the preserved features of authenticity and quantity, and highlight and reveal the cultural value within the scope of the preserved authenticity and quantity (Kutut, 2014).

In the preservation-restoration mode, the non-valuable inclusions are excluded, deposition or removed authentic elements are returned to their original location, repetitive elements are formed following the authentic ones (i.e., using materials, shapes and execution techniques of authentic composition and shape), and lost connections between authentic items are restored.

In the preservation-restoration mode, only the cultural value of the remaining part is highlighted and revealed.

In the preservation-restoration mode, only the following management works are performed:

- technical research – to assess the technical condition, to determine the negative factors of decomposition and decomposition processes, to evaluate the non-valuable elements by engineering (only those non-valuable elements that determine the total structural stability of the remaining authentic part) and to determine the authentic forming technology,
- scientific research – to reveal lost features of authenticity and quantity and to identify the authentic way of formation and non-valuable elements,
- all types of preservation work,

- precursor of accident exclusion works,
- fragmentary restoration works, that remove non-valuable inclusions and authentically form valuable items,
- types of partial restoration work – anastylosis (assembly of authentic parts and elements into an authentic whole) and relocation (replacement of the authentic place),
- all types of repair work carried out on non-valuable items left behind,
- adaptation works.

The preservation-restoration mode applies to those immovable cultural values, their parts, and fragments, which retain most of the features of authenticity with non-valuable inclusions that do not affect the cultural value of such values, regardless of the surviving scope and composition of such values.

The preservation-restoration mode most often applies to objects of State significance, cultural monuments, and immovable cultural values, located in cultural and complex reserves.

The preservation-restoration mode applies to:

- the immovable cultural property with no preservation mode established,
- the immovable cultural property with the preservation mode as the first stage of management works,
- structure dependencies on any level of physical damage.
- Preservation-restoration mode can apply to:
- the physically damaged archaeological values and parts thereof that are destroyed due to economic activities,
- the memorial sites and parts thereof of any level of physical damage, that are no longer in use,
- the low-physically damaged structures and ensembles of structures with insignificant non-valuable inclusions and parts thereof, the cultural value of which as a whole can be highlighted and revealed by fragmentary restoration works,
- the low-physically damaged, with a small piece of insignificant non-valuable inclusions in the essential areas of complexes of structures and cultural sites, the cultural value of the whole of which can be highlighted and revealed by fragmentary restoration works.

5.2.3. Restoration mode

Restoration mode is a set of particular management works that maintain all the preserved features of authenticity and quality, restore the lost physical and technical characteristics (strength, resistance, protection against precipitation, moisture, cold, etc.), highlights and reveals the lost cultural value, and preserves the priority of the requirements listed to suit today's needs. In the restoration mode, the highlighting and revealing cultural value remove non-valuable inclusions, that fundamentally changes the features of authenticity and quantity, and restores the main lost parts and elements that determine the cultural value and their totality. The restoration mode preserves and reveals cultural value without seeking to reconstruct it as a whole (Kutut, 2014).

Non-valuable inclusions that fundamentally alter the characteristics of authenticity and quantity are those that are incompatible with authentic material and performance technique, that change the type of authentic form, that severely distort the authentic location, scope, and composition, and have no time signs. Non-valuable – parts and elements may be maintained when:

- they determine the constructive stability of the remaining authentic part;
- they do not substantially alter the characteristics of authenticity and quantity.

Only the following management works are performed under the restoration mode:

- all types of research (as a prerequisite for the restoration mode),
- precursor of accident exclusion works – applied only in cases when other management works are not performed and the immovable cultural property is in an emergency condition, and are considered as the first stage of management works,
- all types of restoration work,
- all types of reconstruction work (except for the reconstruction of the immovable cultural values as a whole),
- all types of repair work,
- all types of adaptation work (except regulated new construction).

Reconstruction of parts and elements of immovable cultural property may be carried out only based on the remaining features of authenticity and quantity, indisputable scientific facts, and documents that accurately record the lost parts of such property.

All solutions and measures (innovations) must harmonize with the whole of authenticity, where any kind of repair and adaptation work is carried out on the remaining non-valuable inclusions. This means that these solutions and measures (innovations) must not change the authentic types of planning, spatial and volumetric structural structures, types of facades and interiors, types of relief, paving and silhouettes, types of constructive and technological structures. The inherent characteristics and measures of the composition must also be applied.

Innovations must not deviate with authentic materials and performance techniques, but at the same time differ from them.

Necessary researches must be carried out where any kind of repair and adaptation work is carried out on protected parts and elements of authentic immovable cultural property. Preservation mode must be applied to prevent damage to the authentic materials at industrial and exhibition sites, and all solutions and the measures must be in harmony with the whole of authenticity.

Adaptation works can be carried out only when restoration works alone do not make it possible to adapt real cultural values to today's needs.

The restoration mode applies to those immovable cultural values, their parts, and fragments, in which elements of the features of authenticity and quantity have survived, forming an albeit fragmentary remaining as a whole. Based on the remaining features, restoration could recover parts and elements that could show lost cultural value. Such values may contain non-valuable inclusions of various degrees of activity, both unaffected and fundamentally altering the remaining cultural value of such values. The restoration mode is most frequently applied to immovable cultural property.

The restoration mode must apply to:

- the immovable cultural property, if no preservation-restoration mode was established for it,
- the physically damaged structure ensembles.

5.2.4. Restoration-reconstruction mode

Restoration-reconstruction mode is a set of particular management works that restore all the remaining features of the authenticity and quantity of the value and restore the former cultural value of the whole.

In the restoration-reconstruction mode (preserving the priority of restoration requirements), all authentic parts and elements are reconstructed, non-valuable inclusions and innovations non-dissonating with the authentic part are retained, strengthened by new measures, and combined into a unified whole that is adapted to today's needs (Kutut 2014).

In the restoration-reconstruction mode, all cultural value is preserved, revealed, and reconstructed. This mode applies in exceptional cases.

The following management works are performed under the restoration-reconstruction mode:

- all types of research,
- precursor of accident exclusion works – applied only in cases when other management works are not completed and the immovable cultural property is in an emergency condition, and are considered as the first stage of management works,
- all types of restoration work,
- all types of reconstruction work,
- all types of repairs,
- all types of adaptation work.

The reconstruction of the totality of destroyed and decayed immovable cultural property applies only in exceptional cases.

The restoration-reconstruction mode may be applied to the destroyed and decayed immovable cultural values of special social significance, in exceptional cases. The reconstruction of such values as a whole symbolizes the most important events in the history of the nation and the State.

The restoration-reconstruction mode does not apply to archeological values and memorial sites (cemeteries).

5.2.5. Application procedures for modes of immovable cultural property management

The immovable cultural property management modes shall be established by drawing up regulations for the protection of such property. The established modes are specified in the section of the conditions for handling security regulations (Department of Cultural Heritage, 2020).

Following the established immovable cultural property management modes:

- work programs for such values must be prepared,
- the types of management work of such values must be identified,
- conditions for the management and the preparation of projects of such valuables must be issued,
- projects for the management of such values must be coordinated,
- permits for the management work of such valuables must be granted,
- conditions for the management works of non-valuable inclusions contained in such values are set.

The management modes must be specified in special (plans for reserves and nature reserves, national and regional park planning schemes, protected landscape objects, nature, and immovable cultural monuments protection projects) and all detailed planning documents for the values of the protected areas and other areas with immovable cultural values.

If the protected areas are established for the preservation of immovable cultural values, the planning schemes of these areas shall be prepared taking into account the established modes for the management of such values.

When managing immovable cultural values located in protected areas, priority shall be given to the established modes. Such values may not be subject to different management conditions if they conflict with the management mode.

Depending on the extent of protection, the management modes determined:

- for all immovable cultural property of an overall preservation extent,
- only for individual material or structural parts of the real features of the cultural value of the immovable cultural value, where there is a component protection extent,
- only for individual elements with value features of the immovable cultural value when there is a fragmented protection extent.

Depending on the authenticity and quantity of the factors and elements constituting the immovable cultural property, the following may be determined:

- the uniform management mode:
    - for all immovable cultural property of an overall protection extent,
    - for individual parts and elements of immovable cultural property of a component and fragmented protection extent,
- different management modes:
    - for all parts and elements of the immovable cultural property of an overall protection extent,
    - for all parts and elements of the immovable cultural property of a component and fragmented protection extent.

Zoning, according to management modes, can be carried out for all types of large, complex, and multi-stage values, cultural areas, for which draft protection regulations must be prepared following the established procedure.

Typically, zoning by management modes is performed:

- in cultural areas: old towns, historic urban and city areas, ethnographic villages,
- in structural complexes and ensembles: manors houses and folwarks and other estates, monastery complexes and ensembles, palaces and other ensembles, factories and other compounds,
- in archaeological values: in the cultural strata of urban historical areas, physically damaged or economically used hillforts, ancient residential, and other places.

Zoning of damaged or used memorial sites and large, complex and multi-stage structures can also be performed according to management modes.

In all cases where the zoning of immovable cultural property by modes is carried out, the conditions for the management of such property protection regulations must specify all specific material or structural components, elements, and areas of the property and the particular management modes established for them.

The zoning of cultural areas for which the protection regulations projects are prepared following the established procedure shall be indicated in the scheme of management modes of the graphic part of such projects.

The zoning by the management modes of the immovable cultural property with the protected areas established shall be specified in the planning scheme of these areas.

The management modes come into force from the day of drawing up the regulations for the protection of immovable cultural property and are valid until the supplementation and revision of these regulations, which are carried out following the established procedure.

Reasons for changing management modes, protection extent, and zoning according to management modes, can only be a change of the characteristics of the authenticity and quantity of immovable cultural property, i.e.:

- adjustment of such features or identification of new features through researches of such values,
- partial or complete loss of such features due to various causes of extinction.

A change in ownership or purpose of use cannot be a reason for a change in management modes, protection extent, and zoning by management modes. The modes for the management of immovable cultural property shall be amended by the responsible services which have concluded the regulations for the protection of such property based on:
- submitted research reports. Such reports shall be provided by the experts who carried out the researches following the established procedures for project coordination and authorization,
- acts determining damage to immovable cultural property.

The amended of immovable cultural property management modes enter into force after supplementing and clarifying the regulations for the protection of such property following the established procedure.

5.2.6. Implementation monitoring for modes of immovable cultural property management

The implementation of the established, immovable cultural property management modes is controlled by the subdivisions of the cultural property protection authorities:
- preparation of management work programs, determination of types of management work, issuance of conditions for the development of management work and their projects, coordination of management work projects and issuance of permits for management work,
- coordinating the planning documents of protected areas and other areas containing immovable cultural values,
- organizing planning schemes and other materials for protected areas that are established for the preservation of immovable cultural values,
- carrying out other activities provided for in the Staff Regulations.

In all cases where the immovable cultural property is divided into separate property subjects, a general regulation for the protection of such property must be prepared following the established procedure that determines management modes for the entire immovable cultural property (Department of Cultural Heritage, 2020)

When creating separate protection regulations for each part of the property, the management mode (or modes) for that part must correspond to the management mode (or modes) of the whole immovable cultural property set out in the general protection regulation for the part of such property managed.

In all the cases, when management works are planned, but their programs and projects do not comply with the defined immovable cultural property management modes, such programs and projects can not be coordinated, and the conditions and permits for such works can not be issued.

In all the cases, when management works do not comply with the defined immovable cultural property management modes, such management work shall be suspended under the established procedure. If the management work caused the damage to the immovable cultural property, those responsible must compensate for the damage following the procedure established by law: to restore the condition of the damaged part and, besides, compensate for the damage caused.

5.3. Immovable cultural property management works

Before the management of immovable cultural property begins, it is necessary to define the management works and determine the dependence of such works on the cultural value, physical condition, authenticity, and the immovable cultural property management modes established in the protection regulations (Department of Cultural Heritage, 2020)

Management works of immovable cultural values are complex scientific, construction, planting, and other activities aimed to research immovable cultural property, discovering and localizing features of cultural value, preserving, exhibiting, and restoring them.

Management works also aim to identify and stop (eliminate, regulate) the impact of external and internal destructive factors on the immovable cultural value, guarantee its good physical condition and long-term protection against further decay, remove non-valuable inclusions and adapt this value to today's needs, preserving its composition, scope, and features of cultural value.

The immovable cultural property management works are:

- research,
- preservation,
- restoration,
- reconstruction,
- precursor of accident exclusion,
- repair,
- application.

The research works specify, detail, and supplement the features of cultural value and social significance, which are determined during the accounting of immovable cultural values and are recorded in the accounting documents of such values.

Preservation, restoration, and reconstruction works preserve, exhibit, and restore or repeat the following features of the cultural value of the immovable cultural property:

- authenticity-material, form, technique, place, function, timestamps, original idea,
- quantity-volume, composition.

Precursor of accident exclusion, repair, and application works eliminate deformations and technical defects of immovable cultural property, improve physical condition and performance, adapt such property to today's needs, preserving the composition and scope of these property protection regulations, the main features and territories of cultural property.

For these works carried out on the immovable cultural property, the regulations for the protection of such property define conditions which define:

- the type, location and scope of the works,
- materials, products and constructions to be used,
- permissible new forms and their relationship to authentic parts and elements of the value,
- necessary additional research, preservation, restoration works.

The management works of immovable cultural property are selected according to the specifics and importance of the objects of protection, the type of such property, the current physical condition and the established management modes, and the extent of protection, determined in the regulations on the protection of immovable cultural property. The objects of protection are immovable cultural values, including immovable cultural values declared as cultural monuments. Management works are performed under permits issued following the procedure established by state institutions. Only certified specialists and companies holding licenses specializing in the management, research, and design of the immovable cultural property monument works may carry out researches, preservations, restorations, and reconstructions of immovable cultural property and prepare the conditions, programs, and projects for such works.

The immovable cultural property management works, and their conditions are determined by drawing up regulations for the protection of such property. Management works and their conditions are established for the following immovable cultural values:

- large, complex and multi-stage values of all kinds,
- all sorts of values, when their overall (whole object) reconstruction is planned by creating copies and models,
- cultural sites drawing up individual protection regulations or such drafts are already prepared.

He immovable cultural property management and its conditions are determined by certified specialists of the immovable cultural property protection management, who specialize in monument protection and monument management. Certified management specialists determine the management works and their conditions based on the data of the accounting documents and on-site inspections of immovable cultural property, the acts of technical condition, and the established management modes. Data on previous researches projects prepared and management work performed must also be used. In complex cases, management works and their conditions may be determined based on written conclusions and proposals for management works by certified research and design specialists, monument management specialists, or experts.

The immovable cultural property management works permitted under the management modes, and their conditions determined by drawing up regulations for the protection of this property. The specified licensed management works and their conditions are defined in the section of processing conditions of the protection regulations. Research, preservation, restoration, reconstruction, repair with modifications, adaptation, and precursor of accident exclusion works specified in the protection regulations are detailed and refined (i.e., the exact types and methods of work, specific physical volumes of work, parts and elements handled) are determined in research programs and special conditions for the design of immovable cultural property management work. Management works are detailed and refined, taking into account the current physical condition of the immovable cultural property, the specific needs of the customer, and financing opportunities.

Repair works without modifications and precursor of accident exclusion identified by protection regulations are specified and detailed in the publications of these works. If complex management works are established for immovable cultural values, then such values are zoned according to the management works. In these cases, the main material components and elements must be specified, and specific management works for them must be specified in the management conditions section of the protection regulations for the protection of such values. The management works permitted under the established management modes shall enter into force from the day of drawing up the regulations for the protection of immovable cultural property and shall be valid until these regulations are supplemented and clarified. Permitted management works specified in the protection regulations may be changed only when the management modes, the extent of protection and zoning according to the management modes are changed, supplementing and clarifying the regulations for the protection of immovable cultural property (Department of Cultural Heritage, 2020)

Works requested by property owners, managers, lessees, and clients, or required by other conditions (fire, sanitary-hygienic, environmental protection, etc.), may not be applied if they contradict with the management works and their terms permitted under the established management modes.

5.3.1. Preservation works

Preservation is a complex of scientific, construction, implementation of specialized technologies and other activities, aimed for stopping (eliminating, regulating) the impact of external and internal factors destroying immovable cultural values and assessing in the current situation (i.e., preserving) all remaining authenticity and quantity features of such values.

The immovable cultural property is reinforced with exclusive materials and constructions, protected from further decay, and suitable conditions for their long-term existence and exhibition are created during preservation. Preservation works do not change the historically established and remaining form of such values, regardless of the cultural value of the remaining components, elements, and inclusions, nor do they change the remaining composition and scope of such values.

The leading technologies for the immovable cultural property preservation are:

- **Of the territories** (land surface, slopes, geoplastic elements, communication equipment):
    - installation of water regime control measures: installation of layered, tubular, vertical, circular, horizontal, mixed, fascined, construction drainage,
    - installation of drainage devices: installation of collectors, drainage collectors,
    - installation of water flow protection measures: installation of catch drains, culverts, reinforcement of ditch bottoms with natural materials (sett, gravel, stone pavement, sod),
    - installation of the accompanying measures for water management outside the value areas: installation of top streams, thresholds, locks, pumping stations, filters, wells, forts, aqueducts, ducts,
    - installation of water leakage control measures outside the value areas: installation of protective ditches, embankments, gliding down the feeding basin area and changing the slopes,
    - installation of mechanical fasteners on slope soils: installation of poles, piles, anchors and their rows,
    - elimination of small of possible surface erosion outbreaks: backfilling of subsidence, pits, trenches, potatoes diggings and other small excavations,
    - improving the sanitary condition of the area: removing the dumpsters, landfills, disposal of slurry pits, compost, and other organic waste.
- **Of the structures** (buildings, technological structures, functional equipment):
    - management and installation of groundwater protection measures: reconstruction of the destroyed parts of foundation waterproofing using the former materials and type of waterproofing, impregnation of masonry with waterproof materials, drying of masonry,
    - installation of precipitation protection measures: installation of protective covers and roofs, covering with moisture-proof materials, hydrophobization of the masonry surface, sealing of the roof covering,

    - installation of mechanical reinforcement and stiffening means in building materials and constructions: fixing of foundations by injection, installation of pile foundations and laying of foundations in deformation zones, prosthetics, installation of anchors, anchoring, installation of temples in deformation zones, wall clamping, cracking and filling, gluing,
    - fixing of construction materials by chemical measures: fixing of masonry surfaces by impregnating, impregnation of wood with flame retardants, preservative painting of wood, antierosion protection of metal (painting with rust binders),
    - protection of construction materials and structures from chemical and biological contamination: masonry washing, cleaning, desalination, grooving, wood cleaning, disinfection and impregnation with antiseptics and fungicides, removal of mold, lichen moss, shrubs, and trees,
    - removal of decomposed parts: extraction of rotten bricks, mortars, tiles, and other products, cutting off pieces of damaged wood (rotten, contaminated with wood fungus, damaged by pests), demolition and cleaning off layers of worthless bounced plaster, paint, and varnish,
    - formatting a suitable microclimate: installation of insulation layers and ventilation ducts, openings, installation of heating and air conditioning systems,
    - rescue of construction materials.
- **Of the plantations** (ligneous and herbaceous plants):
    - removal of droughts, windbreaks, shelterbelts, snowfalls,
    - salvage logging of slopes: removal of fallen and toppling trees and bushes, logging of mechanically and biologically damaged trees,
    - improvement of grass cover: repair of existing sod (cutting-off unviable and damaged sod areas, straightening of wrinkles, filling of slots, nailing with stakes), turfing the eroding areas, additional sowing of grass mixtures,
    - improvement of growing conditions: installation of water regime control measures, soil layer replenishment, fertilization, plant pests' control,
    - rescue of individual valuable materials: cutting of dry and broken branches, strains, cleaning of the tree hollows, ruptures, cracks, disinfection and sealing, clamping of the trunk and large branches,
    - improving the sanitary condition of afforested areas.
- **Of the groundwaters:**
    - strengthening of eroding shores of groundwaters using natural materials: paving of shores with stones, backfilling of sett or gravel, turfing of shores,
    - bottom and shore cleaning from sludge and aquatic plants,
    - preservation of hydraulic equipment,
    - improving the sanitary conditions of shores and coasts.

The following preservation methods are distinguished depending on the nature of the preservation of authenticity features:

- granting the required physical characteristics (strength, stiffness, stability, moisture resistance, biological and chemical contamination, etc.) to the authentic material by internal and external means. In this way, large integral immovable cultural values, their separate parts, and elements are preserved,
- isolating the authentic material (wrapping, covering, etc.) from the effects of negative factors by external visible means. In this way, small physical volumes of immovable cultural property and residues of immovable cultural property formed from weak, susceptible, and non-durable materials are preserved.

Preservation works are carried out on the immovable cultural property, its parts and elements, which have retained most of the features of authenticity, with no or almost no non-valuable inclusions, i.e., when they do not need to be restored or reconstructed, or there is no data for these works, and precursor of accident exclusion, repair and adaptation actions may damage their cultural value. Immovable cultural property with the following characteristics must be preserved when:

- cultural values or thereof are in poor and emergency physical condition,
- their physical condition or their parts may deteriorate due to the effects of destructive factors.

Preservation works usually are the first stage of restoration work. Preservation works are carried out in those immovable cultural values or parts thereof where the preservation or preservation-restoration management modes have been established. All the preservation works must be carried out based on data from fixing and engineering researches (Department of Cultural Heritage 2020).

Preservation for individual types of immovable cultural property is defined by the preservation technologies applied to the main constituents of such property, i.e.:

- preservation of archeological values and memorial sites (cemeteries, battlefields, etc.) is the preservation technologies applied to their territories,
- structure preservation – is the application of building preservation technologies,
- preservation of cultural sites, complexes, and ensembles of structures and memorial sites (estates) is a complex application of preservation technologies for their territories, structures, plantations, and water bodies.

5.3.2. Restoration works

Restoration is an implementation of complex scientific, construction, specialized technologies, and other activities aimed to restore the loss of physical and technical features of the immovable cultural values, and to preserve, highlight, and reveal the preserved and damaged features of the cultural value of such values.

Restoration reveals authentic parts and elements of immovable cultural values, removes non-valuable inclusions that fundamentally change the features of authenticity and quantity, restores missing items and their connections based on data in kind, and creates conditions for the exhibition of such values. Such values are also reinforced in authentic ways, using materials analogic to authentic ones or using modern technologies, if the authentic ones are not sufficient, and adapted to today's needs without changing the remaining features of authenticity and quantity. Restoration works change the historically formed and preserved form of such values, highlighting their cultural value (Kutut, 2014).

The leading technologies for the immovable cultural property restoration are:

- **Of the territories** (land surface, slopes, geoplastic elements, communication equipment):
    - elimination of the mechanical damage of the surface caused by subsequent human activities to the current ground level: landfilling the ditches, canals, quarries, pits and other extensive excavations, excavation of embankments, heaps and others,
    - adjustment of natural surface unevenness caused by subsequent natural exogenous processes to the current ground level: landfilling of ditches, arroyos, foredeep and other hollows with engineering-based soils, removal of natural humps,
    - demolition of non-valuable structures: demolition of temporary structures, removal of remains of non-valuable structures, of temporary roads and paths, of dissonant pavements (asphalt, concrete) and replacement with materials of the same or similar remaining authentic paving materials, leveling of the demolished non-valuable structures,
    - localization and uncovering of valuable land surface shapes, geoplastic elements: scraping of top layers, preservation of exposed parts,
    - localization and excavation of pavements of valuable communication equipment (roads, paths, squares): scraping of topcoats, preservation of exposed parts, accurate restoration of non-remaining pavement elements according to the preserved elements,
    - reconstruction of destroyed parts and fragments of geoplastic elements (dams, terraces, observation decks, decorative hills, ditches, etc.) and communication equipment according to the preserved forms using the same materials and products and constructive solutions as in the remaining parts.
- **Of the structures** (buildings, technological structures, functional equipment):
    - localization of structures, architectural forms and decor elements, their remains and traces: exposure by probing of beam sockets, arches, and lintel feet, reveals, frames, chimneys, polychrome painting areas, molding elements, their fastenings and prints, stoves, fireplaces, etc.,

- uncovering of localized valuable structures, architectural forms and decor elements to an authentic surface: demolition of masonry overlays, of non-valuable plaster layers and paneling, mechanical removal of non-valuable painting and varnishing layers, dismantling and cleaning of openings and canal fillings, installation of exposure by probing,
- demolition of non-valuable extensions and superstructures,
- engineering-based demolition of non-valuable structures: walls, bulkheads, columns, buttress, ceilings, beams, etc. dismantling, dismantling of temporary supports,
- removal of non-valuable products: removal of windows, doors, stairs, stoves, floors, etc.,
- complete reconstruction of the systems of moisture protection, insulation, ventilation, and sound insulation according to the remaining parts and fragments: reconstruction of the waterproofing of entire (continuous) foundation; cleaning of the drainage system and restoration of missing elements according to the remaining elements and system connection to drains or receivers; reconstruction on and discloser of the insulation layers, of floor fillings and ventilation ducts and openings; reconstruction of chimneys, of rain collection elements according to surviving features or analogies,
- reinforcement and stiffening of structures using traditional measures: gluing and augmentation of fallen bricks, stones, replacement of fragmented mortar, reinforcement of beams and lintels, reinforcement of arches and domes with cross reinforcement and wedges, displacement of support beams and rafters, returning of the fallen beams and slabs to the original places; reconstruction of strings and temples, re-assembly and tightening of knots, stitching and filling of cracks,
- replacement of decomposed structures, products and articles that are no longer technically possible to be preserved and reinforced by traditional means, with exact replicas: re-masonry of foundations, walls, and fragments of bulkheads and columns, arches, dome openings and lintels, replacement of the wooden beams, posts, rafters, wall replacement of beams and columns with new ones,
- banding of structural remains with identical materials, products, and structures: bricklaying of arches, domes and lintels on remaining feet or imprints; installation of new beams (made according to the former) in remaining or restored nests; reconstruction of destroyed parts of foundations and walls between remaining fragments on the remaining lower parts or foundations; reconstruction of columns and buttress on the remaining lower sections to the supporting structures,
- return of fallen elements to the original place: gluing of parquet boards, ceramic tiles, paving stones, tiles, fixing of tiles, stairs, railings, assembly, gluing and fixing of gluing, carving and metal decor elements,

  - strengthening of decorative finishing: removal of wall paintings, fabrics, wallpaper fragments, strengthening of the base, gluing with fabric, gluing and gluing from pieces,
  - production of copies of duplicate elements according to the materials, forms, and performance technique of the surviving parts, placing copies in the places of destroyed elements.
- **Of the plantations** (ligneous and herbaceous plants):
  - sanitary cuttings throughout the green area,
  - selective cuttings: removal of gravity-controlled trees and bushes, cutting felling of low-value, diseased and old trees, and bushes, removal of trees and bushes subsequently planted,
  - removal of valuable ill and old trees and bushes and planting new plants of the same species in their places,
  - replanting of missing species of identical trees and bushes in bioconstructive elements: massifs, cavities, groups, tree circles, tree nests, tree rows and alleys, hedges,
  - giving original (authentic) geometric shapes to tree crowns and bushes by pruning and trimming,
  - rescue of solitaires (i.e., the most composite lonely trees),
  - management and reconstruction of grass cover and flower beds: removal of worthless later inserts (arable land, soils, flower beds), leveling of uprooted stumps, installation of meadows, lawns and flower beds in the former places,
  - Restoration or restoration of the original (authentic) drainage system.
- **Of the groundwaters:**
  - mass of water change: darning the reservoirs and their refilling,
  - regulation of the water horizon to the initial (authentic) level: refilling the empty groundwaters, raising or lowering the water level,
  - dredging the groundwaters, adjustment of shoreline contours to original (authentic) sizes and shapes,
  - reconstruction of elements of the groundwaters: formatting the peninsulas, islands, isthmus, bays, canals, bends, cascades, waterfalls, thresholds, molding the fords from natural or the same as authentic materials,
  - restoration of hydraulic equipment,
  - installation of decorative hydraulic equipment and small decorative structures near water bodies: aqueducts, basins, fountains, gratings, bridges, etc. restoration and restoration.

Restoration is not intended to preserve and exhibit only one stage of historical development, the authentic whole. The restoration of immovable cultural property must preserve the valuable parts and elements of all stages, and the elements exhibited from the various periods must form a harmonious whole, reflecting the historical development of such property.

In cases where the previous elements are revealed by removing the later ones, the following principles must be observed:

- the removable element must have no cultural value. In exceptional cases, where it is necessary to disclose multi-stage historical development, fragments of elements of cultural value may also be removed. In such cases, the committee of certified experts determine that the item to be exposed is of higher cultural value than the removable item,
- he exposed item must be in good enough physical condition to prevent it from being exposed when exposed.

Valuable parts and elements are all parts and elements formatting the original, as well as historical changes and additions, which have features of cultural value in themselves or together with the elements of previous stages form a whole with such features.

Non-valuable inclusions that fundamentally alter the characteristics of authenticity and quantity are ones that are incompatible with authentic material and performance technique, change the type of authentic form, severely distort authentic location, scope, and composition, and have no time stamps.

Non-valuable inclusions – parts and elements that can be left:

- when they determine the proper physical condition of the remaining authentic part,
- when they do not substantially alter the characteristics of authenticity and quantity.

Missing elements and connections can be restored during restoration only in the following cases:

- when identical repetitive elements are missing. In such cases, exact copies shall be made of the remaining authentic elements,
- when it is no longer technically possible to preserve the elements (i.e., when the material is completely decomposed or irreversibly lost its physical properties). In such cases, exact copies of the elements shall be made,
- when the definite marks (traces) of the former elements have survived in kind, and the connecting parts between them are missing. In these cases, accurate models are made based on the surviving signs.

All the new elements formed in the above cases must not differ or may differ slightly from the authentic parts and elements of the values. All other new elements installed in the immovable cultural property (modern measures of reinforcement, elements resulting from adaptation and repair work, etc.) must be compatible with and distinguishable from such property.

The following types of restoration are distinguished according to the scope of work:

- fragmentary restoration – separate restoration technologies performed in separate parts and individual elements of immovable cultural property,
- comprehensive (whole object) restoration is a complex of restoration technologies implemented throughout the immovable cultural property.

Restoration works are carried out in those immovable cultural values and their parts of the most survived features of authenticity and quantity that form the whole cultural value. Still, there are many non-valuable inclusions of varying degrees of activity that distort and damage such cultural value. In this case, the restoration must be performed:

- when preservation works cannot highlight and reveal signs of cultural value distorted by worthless inclusions,
- where many valuable authentic elements and in-kind data have survived to restore damaged features of cultural value,
- when repair and adaptation works may substantially damage the remaining features of cultural value.

Restoration works shall be performed in those immovable cultural values or parts thereof with the established management modes of preservation – restoration (only fragmentary restoration is possible under this regime), restoration, or restoration – reconstruction. All restoration work must be carried out based on data of fixation work, historical, artistic development, and engineering technical researches. If these researches are not sufficient, additional special research may be performed.

Restoration of immovable cultural property and parts thereof may be carried out only based on value data, accurate iconographic materials (surveying drawings, sharp photographs). And under computed models, that are based on remaining exact marks (traces) and analogy (if such models can be) at the same time.

Restoration cannot be based on hypotheses and inaccurate iconographic material (drawings, engravings, etc.) or solely based on analogies or written data from historical documents(Kutut, 2014)

Restoration of individual types of immovable cultural property is defined according to the restoration technologies applied to the primary material components of such property, i.e.: (Kutut, 2014)

- restoration of archeological values and memorial sites (cemeteries, battlefields, etc.) is the application of restoration technologies to their territories. Only fragmentary restoration applies to these types of values.
- restoration of structures is the application of restoration technologies for structures. A comprehensive restoration (of the whole object) must be applied. For structures of small physical volume,
- restoration of cultural sites, complexes, and ensembles of structures, memorial sites (estates) is a complex application of restoration technologies of their territories, structures, greenery, and water bodies. Memorial sites must be subject to a comprehensive restoration (of the entire site).

5.3.3. Reconstruction works

Reconstruction is a complex of scientific, construction, and other activities aimed to re-form the lost main features of the cultural value of immovable cultural values. All the components and elements of the surviving and lost immovable cultural values are preserved, returned to their original place, accurately replicated, or newly created, during the reconstruction. And they form a unified whole, showing the former cultural value of the totality of such values.

Reconstruction works form the ancient common form of values based on the surviving remains of such values, or such values may be re-formed without changing their remaining structure (in the case of transfers). Reconstruction is the management of immovable cultural property that is used infrequently (partial restoration) or in exceptional circumstances (total recovery)(Kutut, 2014).

The leading technologies for the immovable cultural property reconstruction are:

- **Of the territory** (land surface, slopes, geoplastic elements, communication equipment):
    - reconstruction of the original (authentic) microrelief of the area according to the data of complex research using local soils: backfilling of pits and excavations, harvesting of humps and mounds, the formation of slopes, gliding down according to the altitudes of the original (authentic) microrelief (applicable in the absence of cultural layers),
    - creation of the initial (authentic) profile and contour of the slope using engineering-based primers,
    - reconstruction of destroyed geoplastic elements and communication equipment according to complex research data: installation of observation decks, terraces, decorative and water drainage dikes, hills on the former sites, maintaining the original (authentic) forms and using the same soils and construction structures, roads, paths, and squares installation on the previous places, keeping the former routes and sizes and using the same coatings (materials and products) and their installation structures.
- **Of the structures** (buildings, technological structures, functional equipment):
    - anastylosis: the assembly of remaining authentic parts and elements into an original (authentic) whole, using traditional construction techniques and modern connections (applies only to stone block and log buildings and building accessories),
    - relocation: the dismantling of the terrestrial part of the structure and adequate assembly at another location (applicable only in cases where preservation in an authentic area is no longer possible),
    - dismantling and replacement of broken structures that are no longer technically possible to be preserved, restored or reconstructed,

    - new construction is regulated according to the data of complex researches, restoring the planned, spatial, volumetric structures, facades, and interiors precisely, using the same or close to the original (authentic) building materials, products and constructions and applying similar performance techniques.
- **Of the plantations** (ligneous and herbaceous plants):
    - regulated landscaping according to the data of complex researches by precisely restoring all bioconstructive elements of ligneous plants (arrays, cavities, groups, tree wheels, tree nests, tree rows, alleys) and decorative items (solitaires, hedges, groups of ornamental shrubs) and planned structure of plantations. Sizes, contours, and density of the elements, as mentioned earlier, when planting the primary (authentic) species.
- **Of the groundwaters:**
    - excavation and filling with water of ponds, reservoirs, canals, and ditches,
    - reconstruction of the hydrotechnical mode: formation of leaks, excavation or installation of tributaries, sources, and drains, reconstruction, restoration or installation of a drainage system,
    - reconstruction of hydrotechnical equipment.

Restoration work must replicate the following features of the authenticity and quantity of immovable cultural property precisely: material, form, a technique of performance, location (excluding transfer), scope, and composition.

These features must be identified and demonstrated by detailed and complex researches. Modern reinforcement materials and technologies, various connectors of authentic parts and elements, and other additional advanced measures can be used to reconstruct the immovable cultural values. Reconstruction can thus replace individual authentic items that can no longer be saved.

The following methods of reconstruction are distinguished according to the nature of the preservation of authenticity features:

- anastillosis – is the collection of remaining authentic parts and elements of immovable cultural property into the original (authentic) whole or their return to the unique place,
- relocation – means the dismantling and adequate re-formation of immovable cultural property in another location,
- the creation of copies and models – is the re-formation of an unexplored immovable cultural value, accurately reproducing the features of its cultural value.

Immovable cultural property and parts thereof, reconstructed through anastillosis and relocation, do not lose their cultural value. Parts and elements of immovable cultural property, reconstructed by the creation of copies and models, lose their cultural value. Values that contain such reconstructed parts and elements are zoned according to the management modes. The non-remaining immovable cultural values reconstructed through the creation of copies and models have no cultural value, but the values restored in this way have a social significance.

The following types of reconstruction are distinguished according to the scope of work:

- partial restoration – separate reconstruction technologies performed in separate parts and individual elements of immovable cultural property,
- total (whole object) reconstruction – is a complex of reconstruction technologies performed on the entire immovable cultural property.

Partial and total (whole object) reconstruction by anastillosis must be applied to all immovable cultural property containing value data for this work and is technically possible to do so (i.e., where it is possible to place the authentic part and elements in the original place without damaging the authentic material and shape). Partial and total (whole object) reconstruction by relocation can be applied only to the immovable cultural values that no longer can be preserved in an authentic place due to natural factors (floods, landslides, etc.). Large-scale earthworks are intended (construction, road construction, mining, etc.) or due to particularly unfavorable socio-economic conditions (no emergency values are used) and if technically possible (i.e., when authentic parts and components can be dismantled, lifted, transported and reassembled without compromising the authentic material and forms). Partial reconstruction (where individual elements are reconstructed) by creating copies and models is an integral part of the reconstruction work to ensure that all new elements do not differ or may differ slightly from the authentic parts and elements of the values.

Total (whole object) reconstruction by creating copies and models is applied only in exceptional cases. Each case of reconstruction of immovable cultural property shall be determined by the conclusions of the commissions of certified experts and the decision of the supervisory authorities. Exceptional circumstances apply to the destroyed and decayed immovable cultural values of extraordinary social significance, the reconstruction of which symbolizes the most important events in the history of the nation and the state.

Reconstruction works are carried out in those immovable cultural values or parts thereof of the management modes of preservation – restoration (only partial reconstruction is possible under this mode), restoration (all types and methods of reconstruction are possible under this mode, except for total reconstruction by creating copies and models) or restoration – reconstruction(Department of Cultural Heritage, 2020)

Immovable cultural values and their parts can be reconstructed only based on research data. Management works performed based on hypotheses, and inaccurate iconographic material (drawings, engravings, etc.) or the basis of written data from historical documents are not reconstruction work. Management works that do not replicate precisely the features of authenticity and quantity of decayed immovable cultural property or parts thereof are thus not restoration works.

In exceptional cases, regulated new construction may be applied during the reconstruction of the historical image. Such works create a less precise model, which repeats the main features of the authentic form and quantity of the non-remaining real cultural value. All value and historiographical data must be used, based on analogy and hypotheses and conclusions of scientific theoretical work. Regulated new construction programs and projects of the historic image reconstruction must be publicly discussed.

Reconstruction for individual types of immovable cultural property is defined by the reconstruction technologies applied to the primary material components of such property, i.e.:

- reconstruction of structures – application of reconstruction technologies;
- reconstruction of cultural sites, memorial sites, complexes, and ensembles of the structures is a complex application of technologies for the reconstruction of their territories, structures, plantation, and groundwaters. Cultural and memorial sites (excluding estates) are subject to only partial reconstruction.

Reconstruction of archeological values is not carried out.

5.3.4. Precursors of accident exclusion works

Precursors of accident exclusion works are construction, landscaping, and other activities of the purpose to stop the rapid decay of immovable cultural values (accidents, collapses, etc.) and to establish such values in the existing situation for a specified period.

The precursor of accident exclusion works strengthens all parts and elements of immovable cultural property by modern external (visible) measures, regardless of their cultural value and degree of survival, and create temporary conditions that do not endanger human life, health or the environment. Precursors of accident exclusion work can change the historical and surviving form of such values by supplementing it with temporary external fasteners or removing emergency status elements. Only those parts and elements of the emergency condition of immovable cultural property which endanger human life and health (i.e., the parts and elements are in a state of collapse) and which can no longer be technically reinforced (i.e., when the material is completely damaged) may be removed during the precursors of accident exclusion work (i.e., content is degraded or irretrievably lost its physical features). In cases where the removal of valuable parts and elements is unavoidable, it is mandatory to:

- minimize the amount of material destroyed. Valuable parts and elements must be dismantled with as many authentic elements as possible remaining so that as much of the piece as possible can be reconstructed using anastillosis;
- capture the parts and elements to be destroyed;
- reconstruct removed parts and elements according to prepared and agreed on projects. Non-valuable inclusions must be removed in cases where they are or may be the cause of accidents. It is not possible to remove non-valuable inclusions that determine the total constructive stability of the remaining authentic part.

The precursor of accident exclusion works are the first stage of other management works: preservation, restoration, reconstruction, and repair, and are performed for a limited period (up to 5 years). At the end of the deadline, preservation, restoration, reconstruction, or repair work must be started, and the temporary fasteners must be dismantled or left (long-lasting and constructively necessary pins may be withdrawn, which do not substantially alter the cultural value of the immovable cultural property) (Department of Cultural Heritage, 2020).

The main technologies of precursor of accident exclusion works of immovable cultural values are:

- **Of the territory** (land surface, slopes, geoplastic elements, communication equipment):
    - installation of human safeguards: fencing of collapsing slopes, quarry pits, ditches, installation of temporary bridges above them,
    - installation of drains: excavation and reinforcement of canals, ditches,
    - use and installation of water receivers: use of permeable rock layers of deeper rivers, streams, lakes (i.e., diversion of water flows to natural intakes), excavation of reservoirs and ponds,
    - installation of water regime management aids in value areas: installation of highways, thresholds, locks, pumping stations, filters, wells, culverts, dams, aqueducts, ducts,
    - fixing of slopes by visible (external) mechanical and biological means: installation of structural terraces, retaining walls, fences, braids, prisms, pole barriers, screens, planting of trees and shrubs,
    - removal of additional loads on slopes and their upper parts: demolition of structures, removal of large boulders and torn pieces of soil,
    - gliding down the collapsing slopes: leveling, terracing, scraping of the upper part (cliff). Applicable when there are no cultural layers.
- **Of the structures (**buildings, technological structures, functional equipment):
    - installation of safety equipment: installation of enclosures, fences, roofs, nets,
    - support of load-bearing structures: support of beams, ceilings, lintels, vaults, staircases with wooden and metal supports (beams, logs, metal profiles, constructions); masonry of poles; support of sloping walls, partitions, columns, fences with wooden, metal supports, masonry butters, installation of tripwires,
    - tightening of load-bearing structures by visible (external) means an installation of clamps, temples, strings, fasteners,
    - removal of additional loads: removal of superstructures, partitions, furnaces, floor fillers, rubbish,
    - repair of existing roofs or installation of new roofs,
    - covering of openings: covering of windows, doors and other external openings with panels, masonry,
    - dismantling of collapsible structures and parts of structures, which are no longer technically possible to preserve and restore, after fixing the goals (measurements) of valuable structures, products, elements and parts of structures,

    - covering of elements of decor and functional equipment (wall painting, gilding, molding, carving, stoves, fireplaces, stairs, etc.) with moisture- and frost-proof and impact-resistant materials: panels, polyethylene, stone wool, masonry,
    - dismantling and relocation of valuable removable products (windows, doors, shutters, gates, fittings, parquet boards, wood panels, steps, railings, etc.), decor, and functional equipment elements.
- **Of the plantations** (ligneous plants):
    - installation of human safeguards – fencing of falling trees,
    - trimming of large turning trees, which are no longer technically possible to support, and cutting of large, fragile branches,
    - support of valuable tree trunks and large branches, installation of tripwires, and mandrels.
- **Of the groundwaters**:
    - installation of human safeguards: fencing of eroding shores, installation of temporary bridges, discharge of heavily polluted water,
    - fixing of beds and banks of running waters (rivers, streams, canals, ditches): construction of half-dams (groynes), dams, barriers, curtain (inlets) walls, supporting structures,
    - fixing the shores of standing waters (lakes, reservoirs, ponds) – installation of concrete and reinforced concrete slabs on the coasts.

The precursor of accident exclusion work must be carried out in all emergency immovable cultural property and its parts, where no other management work is planned shortly, regardless of the cultural value of such property, degree of survival, type of property, and established management modes. All precursors of accident exclusion work must be carried out based on data from fixing and engineering researches. The precursor of accident exclusion works for individual types of immovable cultural property are defined according to which precursor of accident exclusion work technologies are applied to the primary material components of such property, i.e.:

- precursor of accident exclusion works of archeological values and memorial sites (cemeteries, battlefields, etc.) – the application of precursor of accident exclusion works technologies in their territories,
- precursor of accident exclusion works of structures – is the use of techniques of the precursor of accident exclusion works for structures,
- precursor of accident exclusion works of cultural sites, complexes and ensembles of structures, memorial sites (estates) – a complex application of precursor of accident exclusion works technologies of their territories, structures, plantations, and groundwaters.

Studies of historical artistic development, archeology, history, art history, architecture, polychrome, urban planning, landscape, stylistics, building evolution, evaluation of plantations before repair works must be carried out by minimizing the amount of authentic material destroyed (Kutut 2014).

5.3.5. Repairs

Repair is a construction, landscaping and other activity of the purpose to partially or entirely restore (recover) lost or form new (meeting the requirements of normative construction documents) physical and technical characteristics (strength, stability, resistance to moisture, thermal insulation features, etc.) of immovable cultural property and to improve the conditions for the use of such values.

The composition and scope of the immovable cultural property and the main features and territory of the cultural property must be preserved during the repair. The valuable load-bearing structures of the structures must be strengthened first, and the replacement of broken parts and elements without changing their former position and shape. The repair works do not fundamentally change the historically established and surviving form of such values, regardless of the cultural value of the surviving components, elements, and inclusions (Kutut, 2014).

The main technologies for the repair of immovable cultural property are:

- **Of the territory** (land surface, slopes, geoplastic elements, communication equipment):
    - general leveling of the land surface without changing the micro-relief of the area: gliding down the area, rearranging the local soil, refilling and spreading of additional soil, removal of excess soil, soil compaction,
    - change of profiles of communication equipment (roads, paths, squares) without changing the routes: general leveling of the pavement, change of longitudinal and transverse profiles, installation of excavations and embankments, change of widths of roads and paths,
    - improving the performance of communication equipment: leveling and fixing of kerbsides, replacement of pavement with stronger ones, installation of new pavement, installation of ditches, culverts, curbs, sidewalks, the lighting of the kerbsides,
    - repair of existing water regime measures: repair of various drainage systems, collectors, receivers, highways, thresholds, locks, pumping stations, filters, aqueducts, ducts.
- **Of the structures** (buildings, technological structures, functional equipment):
    - installation of groundwater safeguard measures: installation of construction drainage and rainwater, installation of waterproofing of foundations,
    - installation of rain safeguard measures: installation of drainage system (rainwater, downspouts, gutters, revisions), tinning of chimneys, cornices, balconies, window sills and other protruding elements, installation of rainboards, installation of snow traps,), replacement of damaged roof coverings (tin, tiles, asbestos-cement sheets, plates, etc.) of fragments or the whole of installation of electric heating of roof and drainage system elements, installation of floors, cladding of the plinth with stone slabs,

- removal of finishing materials and products in poor technical condition and replacement them with new one of a better technical characteristics: hammering of the bounced, cracked, and uneven plaster, re-plastering; coating and sanding of plastered surfaces; replacement of wooden cladding; replacement of wood floors (boards, parquet), shaving, planing, varnishing, and painting; tiling and overlaying the stone floors; sanding of mosaic floors, polishing; sealing of leaking windows and doors (replacement of elements and fittings, glazing, installation of the third glass, sealing with polymer or natural sealants), replacement of damaged (rotten, wood fungus infected, damaged) windows and doors with new ones; replacement of stair elements (stairs, steps, raisers, railings, handrails) with poor technical condition; cleaning of paints, varnishes, repainting, varnishing; use of new finishing materials (wallpapering, cladding, paneling, tilling, stoning, installing the suspended ceilings). Repair technology does not apply to all decor elements (wall painting, molding, carving, castings, gilding), valuable products or functional equipment elements (stoves, fireplaces, lamps, windows, doors, gates, fittings, etc.),
- insulation of constructions, installation of steam and sound insulation, installation of natural ventilation: thermal insulation of basement, external walls, and roof; installation of steam and sound insulation in ceilings, walls, and partitions; felling or installation of ventilation openings and ducts (masonry installation of tin ducts),
- replacement of broken elements, devices, and equipment of existing engineering networks, installation of accounting devices, construction of additional branches, devices, and equipment,
- arrangement of existing buildings for a new purpose: filling of existing openings and felling of new openings in existing partitions; installation of new barriers; glazing of balconies and loggias, installation of porches.

- **Of the plantations** (ligneous and herbaceous plants):
  - educational and landscape felling: removal of all low-value trees and bushes, leaving the most valuable species and the healthiest plants; thinning of stands; pruning of trees,
  - removal and replacement of all mechanically and biologically damaged trees and bushes with better and more durable plant species,
  - domestication of the afforested area: removal of stones, mounds, stumps, roots; removal of contaminated soil layers; deep hoeing; rolling; soil layer installation.
- **Of the groundwaters:**
  - replacement of shores and bottom of the groundwaters: change of longitudinal and transverse profile of beds and bowls according to hydrotechnical requirements (dredging of the bottom, straightening of beds and shores, etc.); priming of the dry old beds and ponds, dishes of the reservoirs; gliding and reinforcement of the valleys and terraces of the embankments,

- installation of open measures for the replenishment of water mass and improvement of turnovers of the groundwaters: installation of canals, ditches, channels, culverts,
- repair of existing hydraulic equipment.

All the repair works of the immovable cultural property are regulated to ensure the features not to be damaged or only minimally damaged during the repair. Repair works are governed by drawing up and establishing regulations for the protection of immovable cultural property. In the management part of these regulations, the types of repairs allowed, the place and scope of works, materials, products, and structures to be used, maintenance of such works, and necessary research, preservation, and restoration works are included (Department of Cultural Heritage, 2020).

In cases where valuable parts and elements are being repaired or where their value is unknown, it is mandatory to:

- minimize the amount of authentic material destroyed,
- to research the historical, artistic development of repaired parts and elements.

If the researches determine the cultural value of such parts and elements and find sufficient data in kind for preservation and restoration work, the issuance of a repair permit will require the preservation or restoration of individual sections. New materials and shapes compatible but at the same time different from the authentic parts and elements must be sued to repair the non-valuable inclusions.

The following repair works are appointed depending on the nature of the work performed and the impact on the primary material and structural parts:

- repairs without alterations – are periodic small-scale works that reduce physical deterioration. These repairs remove minor defects, deformations, failures, and replace new broken surface layers, products, engineering devices, various equipment, or parts thereof,
- repairs with the alterations – are works that improve the availability of the immovable cultural property or to renovate such property for a new purpose. During this repair, new partition structures are installed in the buildings, elements of engineering systems are modernized, modern functional and engineering components are installed in the territories of the plots, and additional communication equipment is installed.

The following types of repairs are distinguished according to the scope of work:

- selective repair works – are of the repair technologies applied to individual parts and individual elements of immovable cultural property;
- complex repair works – are of the complex of repair technologies applied throughout the immovable cultural property.

Repair works are carried out in immovable cultural property or parts thereof of the established preservation-restoration (only selective repair works of the non-valuable inclusions are possible), restoration, or restoration-reconstruction management modes. All repairs must be carried out based on the recording data. All repairs with modifications must be carried out based on engineering technical research data.

Repairs to individual types of immovable cultural property are defined according to the repair technologies applied to the primary material components of such property, i.e.:

- repair of archeological values and memorial sites (cemeteries, battlefields, etc.) is the application of repair technologies to their territories. Only repairs without modifications and selective repairs (non-valuable inclusions only) with modifications can be performed,
- structure repair is the application of the structure repair technologies. Only selective repairs can be applied for the works of monumental art (of their foundations and foundations,
- repair of cultural sites, complexes, and ensembles of the structures and memorial sites (estates) is a complex application of repair technologies of their territories, structures, plantations, and groundwaters. Only repairs without modifications and selective (non-valuable inclusions only) repairs with modifications can be performed.

Repairs with modifications are prohibited:

- of the archaeological values (except for the repair of maintaining non-valuable inclusions),
- of the memorial sites (except for the repair of the maintaining non-valuable inclusions with alterations),
- of the structures – works of monumental art,
- all other types of immovable cultural property, which retain all or almost all the features of authenticity. That have no or practically no inclusions of cultural value and the scope and composition of which have not changed or have remained virtually unchanged, regardless of the period of their formation and development.

5.3.6. Application works

Application is a construction, landscaping and other activity aimed to adapt the immovable cultural values to today's needs and exhibition, preserving the scope and composition of such values and the main features and territory of the cultural value.

New functional or exposition measures are installed in the immovable cultural values during the application work. Engineering networks, parts and elements of the values are replaced in a coordinated manner according to the functional and technical requirements or supplemented with new ones. Application works can minimally alter the form of historically formed and remaining values to preserve such values by using them for today's needs (Kutut, 2014).

The main technologies for the application of immovable cultural property are:

- **Of the territory** (ground surface, geoplastics elements, communication equipment):
    - change of the microrelief of the area by gliding down: formation of slopes, planes, and hillsides; leveling of microrelief forms and geoplastics elements; pouring of new geoplastic items,
    - installation of exhibition paths and sites,
    - construction of functional equipment and decorative parts of the territory: construction of stairs, benches, waist-bins, toilets, stairs, annotations, playgrounds, works of decorative art,
    - construction of new roads, paths, squares, and sites,
    - installation of the outdoor engineering networks: excavation of routes, installation of networks, construction of collectors, wells, chambers, transformer substations, and other engineering structures,
    - construction of new buildings is regulated.
- **Of the structures** (buildings, technological structures, functional equipment):
    - strengthening of load-bearing structures by mechanical measures without changing the scheme: strengthening of foundations by piles; allocation of foundations; widening of the base of the foundations, joint fastening of building foundations and walls with bowstrings, clamps, straps, fasteners; thickening of load-bearing walls; installation of duplicating beams; installation of permanent supports (brick, metal, wooden), additional fastening of structural units and connections with gaskets, screws,
    - removal of parts and elements of structures bearing of poor technical characteristics (broken, damaged, insufficient strength) and replacement with new ones without changing the scheme: replacement of log foundations with reinforced concrete piles; new bricklaying, assembly from new logs, timber frame of foundations, walls, partitions, openings, domes; replacement of beams, lintels, rafters, moths, columns with new products; replacement of wooden trusses with metal ones,
    - modification of load-bearing structural schemes with poor technical characteristics (insufficient strength, stability, and rigidity): installation of new foundations and walls (where they did not exist); replacement of loam and plaited walls with masonry, logs, frame; replacement of the beam floors domes by panels, monolithic floors; replacement of rafters roofs with frames, trusses; replacement of arched lintels with flat lintels,
    - overlaying, re-assembly of existing engineering networks, replacement of skeletal schemes and systems,
    - regulated dismantling (demolition) of structural parts and elements,

    - installation of new load-bearing and partition structures: masonry and insulation of walls and partitions, installation of ceilings and mezzanines, installation of columns, traffic lights and other supports,
    - replacement of openings and niches: replacement of existing openings and slots; masonry or other fillings of existing openings and niches; felling of new openings and niches; installation of openings for skylights and hatches; installation of lifts and hoists shafts,
    - installation of finishing (where none existed): plating of logs, plastering of masonry, painting of unpainted surfaces,
    - installation of new products, functional equipment, and decor elements: filling of cut and newly installed openings (doors, windows, skylights, etc.); installation of stairs, ramps, elevators, hoists; installation of fireplaces, stoves, installation of platforms,
    - arrangement of functional and exposition measures: furniture display; installation of devices, equipment and apparatus; installation of exposition stands, the arrangement of works of art, etc.,
    - installation of internal engineering networks: construction of systems; installation of new devices and equipment, felling of canals, furrows, niches and openings, masonry or other installation; installation of underground canals,
    - construction of new extensions and superstructures is regulated, blocking with new structures.
- **Of the plantations** (ligneous and herbaceous plants):
    - clear-felling: continuous felling of stands or parts thereof; forming new fields, spaces or contours of stands, silhouette,
    - replanting of degraded and destroyed stands or parts thereof with better and more sustainable species,
    - regulated afforestation: the planting of new trees and bushes or their clusters, forming new biostructural elements (massifs, cavities, rows of trees and bushes, alleys); dividing existing spaces, changing the contours of the stands, silhouette; visually covering inappropriate images,
    - installation of new ornamental greenery: planting and formation of hedgerows, green walls, solitaires; installation of rock gardens, clumps, etc.,
    - installation of special lawns: golf courses, football pitches, etc.,
    - installation of greenery for watering, heating, and lighting of greenery.
- **Of the groundwaters:**
    - backfilling of existing groundwaters,
    - change of the size and contours of existing groundwaters: increase or decrease of ponds and reservoirs; change of routes of rivers, streams, canals, and ditches; change of water level in groundwaters (raising, lowering),
    - regulated installation of new groundwaters,
    - regulated construction of new hydraulic equipment,
    - installation of functional and exposition measures: construction of piers, marinas, the arrangement of quays.

All the application works of such values are regulated to ensure the features of cultural values not be damaged or only minimally damaged during the application of immovable cultural values. Application works are governed by drawing up and establishing regulations for the protection of immovable cultural property. Including the types of adaptations allowed, location and scope of works, materials, products, and constructions used, maintenance of such actions and necessary research, preservation, and restoration work in the part of the conditions of management of these regulations.

The following types of application works are distinguished as per the nature of the work carried out and the extent to which the features of cultural value are preserved:

- installation of functional and exposition measures – are various small works without prejudice to the features of authenticity and quantity of the immovable cultural value. The practical elements of the territory are installed in the remaining value, internal equipment is installed and arranged, exposition measures are assembled or installed,
- installation of engineering networks – it is the construction and installation works of outdoor and indoor engineering networks, during which material of immovable cultural property may be damaged locally (at network locations);
- reconstruction is a large-scale construction and other works that partially transform and substitute immovable cultural property following functional, aesthetic, and engineering requirements. The shapes and sizes of valuable parts and elements and non-valuable inclusions may be changed in a coordinated manner, and they may themselves be damaged or replaced with new or new ones added. During the reconstruction, the load-bearing structures of the buildings are changed, the engineering systems are changed, the planning and equipment of the plot territories are replaced,
- regulated new constructions – is the construction and other works that supplement the real cultural value with the neologisms. The new structure (building, extension, road, etc.) is built in the property, or another element (geoplastic element, bioconstructive element, groundwater, etc.) is installed of a regulated location, scope, composition, materials, products, and form.

All the formed changes and neologisms during the application works are of no cultural value. The installation of functional and exposition measures and engineering networks does not reduce the cultural value of the immovable cultural property.

Performing these works, it is mandatory to:

- install such measures in non-valuable inclusions (if available, or functionally and technically feasible);
- minimize the amount of authentic material destroyed;

- to carry out exploratory research of vulnerable valuable or unknown parts and elements of the required kind of historical artistic development. If the research establishes the cultural value of such parts and elements, the relocation of such measures should be required when coordinating the work projects.

Reconstructed parts of immovable cultural property or in which regulated new construction work has been carried out, lose their cultural value. Values that have been reconstructed and in which regulated new construction work has been carried out are zoned according to management modes. In all the cases, detailed engineering, technical and historical-artistic development researches of all immovable cultural property must be carried out.

Based on the research data, the coordination and approval of the programs of planned works and projects can address:

- to prohibit reconstruction or regulated new construction works. It is obligatory when the cultural value is established, and there is sufficient in-kind data to carry out other management works, or when the proposed works are likely to substantially damage the features of authenticity and quantity or the territory,
- to restrict the scope of a reconstruction or regulated new construction works, to change their place in the values, to determine the conditions and supervision of such works, and to require the preservation or restoration of the remaining valuable parts and elements.

Reconstruction and performance of regulated new construction works are allowed only when it is proved that the immovable cultural property, only after its preservation, restoration, or repair, cannot be used (i.e., does not meet the functional, engineering, technical and other requirements). Reconstruction and regulated new construction works may be carried out in all non-valuable inclusions of the immovable cultural property. In carrying out this work, it is necessary to apply such new materials and shapes that are compatible and, at the same time, different from the authentic parts and elements. Reconstruction and regulated new construction works may be performed only in those immovable cultural values and their parts, where only fragments of the features of authenticity and quantity have survived, which no longer form the whole cultural value (Department of Cultural Heritage, 2020).

Installation of functional and exposition means and engineering networks can be performed in all real cultural values.

Application works are carried out for the immovable cultural property, or parts thereof of the established preservation, preservation – restoration (according to these modes the only installation of functional and exposition measures and engineering networks are possible), restoration (under this regime all types of adaptation works are possible, except for regulated new construction) or restoration-recovery management modes. All application works must be carried out based on the recording data.

All reconstruction and regulated new construction works must also be carried out based on historical-artistic development and engineering technical research data. Application to individual types of immovable cultural property is defined by the technologies applied to the primary material components of such property, i.e.:

- of the archeological values and memorial sites (cemeteries, battlefields, etc.) – is the implementation of technologies for the application of their territories. For these types of values, only the installation of functional and exposition measures and engineering networks, and the reconstruction of the remaining inclusions are applied,
- of the structure – is the implementation of the structure application technologies. For the structures of the works of monumental art – only the installation of exposition measures may be applied,
- of the cultural sites, complexes and ensembles of structures, and memorial sites (estates) is the complex implementation of the technologies for the application of their territories, structures, plantations, and groundwaters. For the ensembles of buildings and memorial sites, only the installation of functional and exposition measures and engineering networks and the reconstruction of the remaining non-valuable inclusions are applied.

Reconstruction and regulated new construction are prohibited:

- for the archeological values (except for the reconstruction of remaining non-valuable inclusions),
- for the memorial sites (except for the reconstruction of remaining non-valuable inclusions; structures necessary for the protection and maintenance of such valuables may be built, in exceptional cases),
- for the structures as of monumental art,
- for all other types of immovable cultural property with all or almost all remaining features of authenticity, that have no or virtually no inclusions of no cultural value, and which have remained unchanged or almost unchanged in scope and composition, regardless of the period of their formation and multi-stage development.

5.3.7. Complex management works

Complex management works – are the whole of various management works of immovable cultural values performed in a complex manner, depending on the cultural value of their components and elements and the extent of protection.

Complex management works are considered to be different works applied to different parts of immovable cultural property, or when various works are applied to one component in a complex way. Complex management work is usually defined by two types of predominant work (maximum physical volume) (Kutut, 2014). The most commonly used complex management works are:

- preservation and restoration,

- restoration and repair,
- restoration and application,
- repair and application.

Preservation and restoration works must predominate for the immovable cultural values that have retained most of the features of authenticity and quantity. The repair and application works must dominate for the immovable cultural values of an only small part of the features of authenticity and quantity or fragments thereof survived, with the remaining non-valuable inclusions of varying degrees of activity.

Complex management work is usually carried out for the high physical volume and composition, complex (consisting of many different types of authentic parts and elements with many non-valuable inclusions), and multi-stage (characterized by long historical development with many transformations) immovable cultural values.

5.3.8. Control of management works

The established management works for the particular immovable cultural property must comply with the management modes set in the regulations for the protection of such property.

The relevant State authorities verify how the planned, performed, and performed management works comply with the management works established in the protection regulations, according to the management modes and works:

- by coordinating and approving research programs,
- by coordinating management projects,
- by issuing permits for management works,
- by signing the acts of performed management works, acceptance of objects for use and other acts,
- by carrying out different activities provided for in the Staff Regulations.

If unlicensed companies and non-certified specialists perform the precursor of accident exclusion, repair, and adaptation works of immovable cultural property, then such works shall be controlled by certified specialists in those fields under copyright supervision. They verify that the work carried out complies with the prescribed handling work and its conditions.

In all cases where the immovable cultural property is subdivided into separate property entities and zoning of such property is established according to the management modes, a general individual protection regulation of such property must be prepared, which determines the management works and their conditions for the whole real estate. When drawing up separate protection regulations for each part of the property, the management of that part must correspond to the management of all immovable cultural property set out in the general protection regulation following the managed part of such property (Department of Cultural Heritage, 2020).

Monument protection authorities do not coordinate research programs and projects of the management of the immovable cultural property (as well as non-valuable inclusions in such property or their territories) that do not comply with the management work, and its conditions permitted by the protection regulations and special design conditions. Nor are acts of acceptance of such works, acceptance of objects for use, and other acts signed.

In all cases where the management works do not comply with the management regimes established in the Regulations on the Protection of Immovable Cultural Property, the management works permitted under these regimes and their conditions, the clients, contractors, and specialists who performed such works, maybe fined under the Code of Administrative Offenses. If such works have caused damage to immovable cultural property, the guilty persons must compensate for the damage: to restore the damaged part and to pay for the damage.

6. Verbal model for immovable cultural property management efficiency determination

The specificity of determining the efficiency of the management of the immovable cultural property will be analyzed in this chapter. It is impossible to explain all the difficulties of assessing buildings as monuments of cultural heritage in a small chapter, therefore, the main issues that reveal the conceptual level and technique of working with these objects, the carriers of intangible cultural heritage, are touched upon here.

Objects are divided into the following types:

- monuments – individual structures, buildings and constructions with historically formed territories (including religious monuments), memorial apartments, mausoleums, single headstones, works of monumental art, objects of science and technology ...;
- ensembles – groups of isolated or united monuments, buildings, and structures of fortifications, palaces, residential, public, administrative, commercial, industrial, scientific, educational purposes, as well as monuments and structures of church significance, clearly localized in historically established territories;
- sites – human-made creations or joint creations of man and nature, including places where folk arts and crafts exist, centers of historical settlements, or fragments of urban planning and development.

Cultural heritage sites are subdivided into the following categories of historical-cultural significance:

- objects of world importance;
- objects of regional significance;
- objects of local importance.

The historical importance of the building as a monument lies in its significance to society. There is no concept of economic life for the building as a monument. The assessment of buildings as monuments of cultural heritage is based on dividing them into groups.

Most of the c – monuments are individual, but there are certain criteria that allow them to be conditionally combined into certain groups. Let's divide all the monuments, taking into account the functional division into six conditional groups:

- *Group 1.* Objects fully oriented to commercial purposes (housing, banks, offices, holiday homes, hotels, retail premises, etc.);
- *Group 2.* Objects partially oriented to commercial purposes;
- *Group 3.* Objects of non-commercial use (museums, culture, art, care institutions, etc.);
- *Group 4.* Facilities for the accommodation of diplomatic, consular, religious services, etc.;
- *Group 5.* Objects oriented on the State goals (government, officials, law enforcement agencies, fiscal bodies, "state employees", etc.);
- *Group 6.* Objects in poor condition or destroyed. A complete reconstruction of which to date is impractical.

The division into groups allows to determine the means of the value and the totality of approaches to assessment relating to each group.

Impact actors. The factors that determine the identification of buildings as monuments are numerous, but they can all be combined into groups of 5 summarizing ones:
- of the creation time,
- of the copyright decision;
- of the structural embodiment;
- of the external factors of influence;
- of the locations, etc.

Time factor. We consider the time factor and its influence.

First of all, this factor affects the total number of monuments: the older monuments are, the fewer of them are in quantitative terms (however, a small amount can only be indirectly related to the value and influence its increase). It should be noted that there is an approximate period for classifying objects as monuments (not less than 40... 50 years).

Secondly, the time factor affects the practical orientation of objects concerning their use in No. 1, 2, 4, 5 groups (the circle of users sharply decreases with age, which can affect the decrease in the value of facilities).

Thirdly, this factor affects the availability of restored and reconstructed elements: the older structure is, the more elements have lost their original state. The number of copied elements affects the value towards reduction.

Fourthly, this factor influences the status of the monument (in general, the status can increase with age, which is only indirectly related to the value directed to the increase). Thus, the time factor can affect both the increase and decrease of the value of the monument.

However, the peculiarities of the determination of the management efficiency are not a function of its age, so the above dividing can only help in identifying a monument (era, style, master, etc.).

The factor of the copyright decision. The architect and creator of a monument may have a well-known name, which affects the value of the object. The value of the object is associated with the "pioneer" solutions, analogs (copies) of which can be either in large numbers (for example, Rastrelli and Montferrand worked very prolific), or absent (for example, single copies of individual construction project decisions of Corbusier, make them valuable).

The copyright decision factor defines an object as a monument and serves to determine the status of the object. The status of an object is associated with easements and prestige, that affect the value of the object. It should be noted that there are unique monuments – buildings of unknown authors, and the determination of the features of management efficiency for them is not influenced by the copyright decision factor but by the factor of the structural embodiment.

The factor of the structural embodiment. This factor is primarily related to the factors of time and copyright decision. And it works in the presence and absence of information about the authors with the obligatory presence of a time factor.

The uniqueness of the structural embodiment defines the object as a monument and serves to determine the status of an object. The status of an object is associated with easements and prestige, which affect the features of management efficiency determination.

Modern building technologies make it possible to reproduce any copies of cultural-historical monuments – buildings, which is the basis for the features of management efficiency determination.

The factor of the structural embodiment can be considered according to the following criteria:

- the uniqueness of the monument;
- urban planning role;
- historical authenticity (preserved in its original form, has minor changes, partially preserved its unique appearance, recreated, completely rebuilt);
- the nature of the decor of facades, interiors (completely preserved, somewhat lost, completely lost, initially absent);
- planning structure (completely preserved, partially changed, completely changed).

However, the value of a monument is a function of its structural embodiment only when the monument is identified as a "pioneer decision". Therefore, those mentioned above can only help when identifying an object as a monument.

The external factors of influence. External factors of influence are diverse and do not lend themselves to a complete listing. There are historical factors, cultural factors, religious factors, etc.

External factors of influence define the object as a monument and serve to determine the status of an object. The status of an object is associated with easements and prestige, which affect the features of management efficiency determination.

The location factors. The location factor is involved both in the formation of the assignment of an object to monuments and directly affects the value of objects that belong to groups No. 1, 2, and 6.

There is a concept of historio-historical location, and all buildings belonging to the historio – historical ensemble.

Location for non-monument properties determines whether there is an entrepreneurial profit or external depreciation for beneficial properties.

Pricing factors. When evaluating historical monuments, the price-increasing and price-lowering factors should be taken into account:

Price-reducing (easements):

- prohibition on alteration of the planning solution of the building;
- normative tinting of facades;
- prohibition on the construction of extensions, superstructures, and basements;
- prohibition on changing external improvement, etc.

Price-raising:

- location;
- prestige;
- guaranteed investment, etc.

The qualitative nature of the factors of the features of management efficiency determination should be noted. Therefore, qualitative (verbal) methods should be used to assess the characteristics of the management efficiency determination, which will be analyzed in chapters 6 and 7.

6.1. Mathematical economics approach to decision making

Decisions made by people predetermine both the life of an individual and the fate of human civilizations. The life of great generals, emperors, kings, khans appear in history books as a sequence of successful or erroneous decisions.

The main difficulty in decision making is choosing the best option, the best alternative. The choice must usually take place under conditions of uncertainty. You can make plausible guesses about the future, but you cannot know exactly what the choice of one or another option will lead to. Also, as a rule, each of the solutions has its attractive sides. Comparison of the advantages and disadvantages of various options, their assessments, according to multiple criteria, is always a difficult task for a decision-maker (DM).

So, uncertainty and multi-criteria are the main difficulties in decisions making. Is it possible to help a person, a DM, in overcoming these difficulties? Can scientific methods and computer systems increase the chances of a person choosing the best solutions (Ginevičius, Podvezko *et al.*, 2007; Turskis, Zavadskas *et al.*, 2009; Ustinovichius, Zavadskas *et al.*, 2006; Ustinovichius, Turskis *et al.*, 2006).

Although decision-making tasks are as old as the world, their scientific study only began in the 20th century. Economists were the first to tackle these tasks. The problem of choice is one of the main ones in economics (Neumann, Morgenstern 1979). The two principal persons in the economy – the buyer and the manufacturer – are regularly involved in the selection processes. The consumer decides what to buy and at what price. The manufacturer chooses what to invest in, what products should be produced and sold.

One of the foundations of economic theory is the provision on the rationality of human choice. Speaking of rational choice is assumed that a decision or a person's action is the result of an ordered thinking process. Economists in a rigorous mathematical form define the term "ordered". Many assumptions about human behavior are introduced, which are called the axioms of rational behavior. For the first time, such axioms are given in the book (Neumann, Morgenstern 1979). Under the assumption that these axioms are valid, a theorem on the existence of a function or utility is proved. Efficiency is the value that a person with rational economic thinking maximizes in the selection process. We can say that utility is an imaginary measure of the psychological value of various goods.

A person, as if, weighs various alternatives on some "internal scales" and chooses from them the more useful one.

Decision-making problems with the assessment of usefulness and probabilities of events were the first to attract the attention of the researchers. The decision formulation is as follows. The decision-maker makes some decisions in a world where the result (outcome) of a decision is influenced by random events beyond the control of a person. However, given the probabilities of events, the decision-maker can analytically determine the most profitable solution.

It should be noted that in this formulation of the problem, the solution options usually are not evaluated according to many criteria. Meaning, the basic description is used.

Initially, the probability of events was considered as objectively existing. Then the theory of usefulness was developed under subjective, human-defined probabilities: the theory of subjective expected usefulness. People estimated the probability of certain events affecting the result (choosing the alternative).

When applying the theory of usefulness, it turned out that people often do not follow its recommendations, behave "irrationally" (concerning the above definition of rationality). Repeated deviations from "rational" behavior have come to be called paradoxes. One of the first widely known paradoxes is the Allais paradox: people consistently make two conflicting choices.

Over the past 30 years, researches by psychologists have shown that human behavior differs significantly from rational behavior (Kahneman, et al. 1982). People use heuristics in their judgments that lead to errors and contradictions.

Attempting to build an axiomatic theory that takes into account the peculiarities of human behavior is the prospect theory (Kahneman, Tversky, 1979). In prospect theory, a function of probabilities is used, instead of possibilities, constructed in a particular way.

Prospect theory avoids the Allais paradox and several other paradoxes. However, when it is applied, new inconsistencies arise, meaning a systematic deviation of human behavior from the behavior prescribed by the theory.

The next step in the development of the theory of usefulness was the multicriterial theory of usefulness (Keeney, Rife, 1981).

Just like the classical theory of usefulness, the multicriterial theory of usefulness (MAUT) has an axiomatic foundation. Meaning, that certain conditions (axioms) are put forward that the decision maker's utility function must satisfy. If the conditions are met, a mathematical proof of the existence of the decision maker's utility function is given in one form or another. There are more axioms in MAUT, and checking the fulfillment of some of them is considered as an independent task.

If the axioms are fulfilled, then this implies a strict conclusion about the existence of the multicriterial theory of usefulness function in a particular form (for example, in an additive way – the sum of the usefulness of estimates by individual criteria). Thus, axiomatic theories have a rigorous mathematical foundation.

6.2. Heuristic methods for decision-making tasks

The application of axiomatic methods requires verification of the fulfillment of the axioms. Such confirmation is often a sizeable independent task. Besides, the construction of the utility function is time-consuming for the decision-maker and is justified if there are a significant number of alternatives. These circumstances served as an incentive for the emergence of a large number of normative decision-making methods that do not have theoretical justification. For many of them, it is common to use the method of weighted sums of criteria estimates. A value of each criterion is determined in one way or another – a coefficient of importance or weight. The usefulness of assessments by individual standards is also determined.

An example of a well-known heuristic multicriteria method is the analytical hierarchy process method (Saaty, Kerns, 1991).

The method uses a pairwise comparison of criteria to determine their relative importance. The results of the comparison in the form of quantitative indicators of importance are entered into matrices. Coefficients of the importance of the criteria and the coefficients of the significance of each alternative for each criterion are determined using these matrices. Also, the alternatives are compared in pairs for each criterion to determine the relative importance of each of them. The weighted sum method is used next: the coefficients of the importance of the criteria are multiplied by the factors of the importance of assessing the alternatives by the criteria and are summed up – this is how the overall usefulness of the alternative is determined. The alternative with the highest utility is declared the best.

Disadvantages of axiomatic and heuristic approaches to decision making. In our opinion, the central problem in decision-making is to help the decision-maker in the complex tasks of choice. Moreover, the help and support should be provided not to a mythical creature, but a person, taking into account the capabilities and limitations of the human information processing system.

From this point of view, both of the approaches presented above can be thoroughly criticized. First of all, in both axiomatic and heuristic methods, it is implicitly assumed that a person as an accurate measuring device is capable of giving error-free information in a quantitative form. In axiomatic methods, verification of a person's agreement with the axioms is either not carried out or requires precise quantitative measurements from a person. For example, with the MAUT approach, the general utility function can have a different form depending on the value of the sum of the weights of the criteria (Keeney, Rife, 1981). The values of the weights of the various criteria are obtained through a series of complex operations performed by a person. It is known from psychological research that human errors are very likely. However, it is not specified in any way at what possible errors this or that type of general utility function is preserved.

In heuristic methods, neither information transformations nor the form of the utility functions is justified. Attempts to substantiate are no more than just non-verifiable statements that a particular method is "applicable", "convenient" for the decision-maker.

The developed facts about the behavior of people of information processing in recent decades, as well as unsuccessful attempts to apply decision-making methods, have led to several piecemeal approaches. Desire to create the appearance for the user that only simpler, high-quality information is required, is common for these approaches.

For example, with the approach of the analytical hierarchy (see above), a person is required to indicate form how much the weight of one criterion is greater than the weight of another in a qualitative ("approximately equal", "more", "much more", etc.). For the scale of verbal evaluations, a range of numerical evaluations is assigned (from 1 to 9), which the person does not know about. This does not take into account that the relationships between words and numbers are different for different people, which is confirmed in experiments.

The approach of the fuzzy set theory is very close to this. The measurements themselves are made in a qualitative form, but then, using an arbitrarily given membership function, the words are assigned numbers.

The omnipotence in making such transformations is evident and unavoidable. There is no reason to rely on the resulting numbers when making decisions.

Examples of such problems are: choosing a strategy for implementation of the reform, selecting a location for an industrial enterprise, choosing the best research project, choosing a product when buying, etc.

All the above remarks are especially significant in the analysis of semi-structured problems widespread in practice (Simon, Newell, 1958).

6.3. Verbal decision analysis

Most researchers of decision making recognize the profound contradictions between the requirements of regulatory methods and the capabilities of the human information processing system.

An attempt to overcome these contradictions is the approach of verbal (ordinal) decisions analysis (Larichev, Moshkovich, 1996; Larichev, Moshkovich 1997; Larichev *et al.*, 2003; Ustinovičius *et al.*, 2010). The methods based on this approach are scientifically based. This rationale is multidisciplinary, with psychological criteria being the main ones.

When approaching a verbal decisions analysis, the following requirements are imposed on decision-making methods.

1. The natural language describing the problem used by the decision-maker and environment should be preserved at all stages of its analysis without any transformations to numbers. This means that a person should work only with information about his subject area. Information on the numerical importance of the criteria, the values of the thresholds of preference and indifference, etc. are not of the subject area.
2. According to psychological research, methods of obtaining information from people should correspond to the capabilities of the human information processing system. This means that no artificial intermediate numerical data, as probabilities, numerical importance of criteria, etc., should be required from a person.
3. Logical changes in the operation of converting verbal variables (assessments of alternatives by criteria) must be mathematically correct. They define any particular activity of the decisive veto.
4. The decision-making methods should provide the measures for checking the information of the decision-maker for consistency. When receiving data from a decision-maker, one should remember about the possibility of random errors, about the stages of training a decision-maker. In this regard, the verification procedures of information for consistency in the course of its receipt are necessary. Besides, the search for contradictions in the information of decision-makers methods and excluding these contradictions are needed.

We will consider how decision-making methods that meet these requirements can be built.

Correct measurements. The use of quantitative measures in decision-making methods has been associated with the hopes that these measurements are close to measures in natural sciences. Thus, the book (Neumann, Morgenstern 1970) states: "Even if today the utilities look non-quantitative, the history of the heat theory may repeat itself and, this time, with unexpected consequences".

In our opinion, decision-making for the unstructured problems belongs to those areas of human activity where quantitative, and even more so, objective methods of measurement have not been developed and are unlikely to appear in the future. Therefore, it is necessary to assess the possibility of making reliable quality measurements.

Let us turn to the methods of measuring physical variables that were used before the advent of reliable quantitative methods of measurement following R. Carnap (Carnap 1971). Two relations were used: E – equivalence relations and L – superiority relations. In this case, there are four conditions that E and L must satisfy:

1. E and L – exclude each other;
2. L – transitively, that is, from A is better than B and B is better than C, A is better than C;
3. For two objects A and B either: A E B, or A L B, or B L A.

It is easy to see that the above-described scheme allows to make relative comparisons of objects according to one of their qualities. For example: measuring temperature. Applying the palm to hot and cold objects, a person also made relative measurements using the binary relations E and L. However. The next step was the need to compare measurements made by different people and at different times, as well as by one person with various objects. This became possible when people agreed on common points of the measurement scale. For example, when measuring temperature, they could determine these points as follows:

1. So hot that you can hardly put your hand on.
2. There is almost no difference in temperature (body temperature).
3. It is so cold that the hand immediately freezes.

These definitions are not very precise, but they already form the basis for agreement. Using such or similar meanings, there is an absolute ordinal (grades are ordered) scale with discrete categories. Measurements come down to classification, where the subject belongs to one of the groups, or it belongs to the interval between grades.

The ordinal scale constructed in this way cannot have many values since they will become poorly distinguishable for persons taking measurements. It is necessary to highlight clear to make t easier to agree equally felt points on this scale and explain in detail what they mean. Therefore, on such scales, there should be detailed verbal formulations of assessments – quality gradations. Besides, these definitions (quality gradations) distinguish the persons who built the scale (for example, they were only interested in very hot and icy objects).

Thus, the assessments on an ordinal scale are determined both by the needs of persons in need of specific measurements (the decision-maker) and by the detectible assessments, the possibility of their description in a form that is understandable to all.

These scales can be used to measure subjective factors, such as well-known organizations, the scientific background of work performances, the novelty of the style of clothing, and others typical for semi-structured problems.

Building a decisive veto. When constructing a rule for evaluating alternatives (decisive veto), it is necessary to use psychologically correct ways to identify the preferences of the decision-maker.

By analyzing axiomatic and heuristic methods, three groups of operations for processing information can be distinguished: operations with criteria, operations with evaluating alternatives by criteria, operations with alternatives.

An operation is called elementary if it cannot be decomposed into other, simpler operations related to objects of the same group (to criteria, alternatives, and evaluating alternatives by criteria).

The following approach is proposed: it is necessary to collect data from psychological researches related to how confident and reliable a person performs a particular information processing operation. If such data can be obtained, then the subjective correctness of a specific normative method can be characterized through the psychological accuracy of the elementary information processing operations included in it.

Elementary operations are defined as (Table 6.1):

1. complicated (C);
2. permissible (D);
3. permissible at a low-dimensional (MC), if the results show that with a small number of objects (criteria, outcomes, alternatives, multi-criteria assessments), the operation is performed by a person is quite reliable, but with an increase in their number it becomes complicated;
4. indefinite (N, NA, ND), if there is not enough psychological research related to these operations, but sometimes a preliminary conclusion can be made about the admissibility (ND) or complexity (NC) of the process while arguing by analogy with already known facts. Table 1 describes three groups of elementary operations with their estimates.

In the works of (Kochinetal *et al*., 2002; Larichev, Moshkovich, 1996; Roizenson, Furems, 2002; Komarovska *et al.,* 2015), this approach has been applied to evaluate information processing operations, most commonly used in decision-making methods. Many of these operations proved to be difficult for humans, as the results of psychological researches have shown the decision-maker admitting a lot of contradictions, using simplified strategies (for example, excluding some of the criteria) while performing these operations. Only a few operations turned out to be admissible in the sense that the decision-maker was performing a small number of contradictions and using complex strategies.

It is important to note that almost all of the allowed transactions were qualitative. For example, a qualitative comparison of two assessments on the scales of two criteria with the decision-maker's answers "better", "worse", "equivalent".

Another example is the assignment of "more likely" qualitative comparative probabilities.

TABLE 6.1. Evaluation of elementary information processing operations.

Operation No.	Elementary operation name	Assessment
01	CRITERIA OPERATIONS	
011	Streetlighting by utility (value)	ND
012	Assigning quantitative criteria weights	C
013	Decomposition of a complex criterion into simple ones	MP
02	OPERATIONS WITH ASSESSMENT ALTERNATIVES BY CRITERIA	
021	Assigning a quantitative equivalent for a qualitative assessment	NC
022	Determination of quantitative assessment by lottery method (construction of a utility curve by criterion)	C
023	Qualitative comparison of changes in ratings on the scales of two criteria	D
024	Determination of the quantitative equivalent of substitution for a pair of criteria	NC
025	Determination of a satisfactory value based on one criterion	ND
03	OPERATIONS WITH ALTERNATIVES	
031	Comparison of two alternatives considered as a set of evaluations by criteria and selection of the best one	MP
032	Comparison of two alternatives, regarded as something whole, and highlighting the best one	ND
033	Finding probabilistic estimates of alternatives	C
034	Assigning alternatives to solution classes	MP
035	Quantifying utility	C
036	Decomposition of complex alternatives into simple ones	MP
037	Assigning Qualitative Probability Estimates	D

The books of (Larichev, Moshkovich, 1996; Larichev, Moshkovich 1997) provide detailed estimates of elementary information processing operations. The reasons for human errors and contradictions, first of all, are the limited capacity of short-term memory, in which the basic operations of comparison and selection are carried out (Larichev, 2002).

The human mistakes and contradictions do not make a person an "intellectual cripple". On the contrary, the social information processing system is perfectly adapted to solving most of the problems that a person faced in the course of his development. A person is also suited to multifactorial tasks with a small number of factors, within certain limits. Besides, a person has a set of heuristics that allow him to solve problems of any complexity, simplifying them in advance and adapting them to his limited capabilities. But some tasks are difficult for humans. Nothing is surprising in the very existence of such problems. After all, humans are biological beings and have their limits on everything. A person cannot jump 10 meters in height, do without water for five days, etc.

Likewise, a person cannot consider many factors without using heuristics. And all heuristics have the following property: they are useful for most cases, but there are cases when they lead to logical errors, contradictions.

The high-quality information and high-quality information processing operations, using logical transformations, make it possible to obtain rules for evaluating and comparing alternatives, that is, a decision rule. Ways to test the system of criteria for independence, also based on psychologically correct operations, are provided for by the methods of verbal decisions analysis. In case of identification of the dependence of the criteria, it is proposed to change the verbal description of the problem to achieve independence of the criteria (for more details see (Larichev, Moshkovich, 1996; Larichev, Moshkovich, 1997). The logical transformations required to compare alternatives have a rigorous mathematical foundation.

Checking for consistency and getting explanations. Errors are one of the vital features of human behavior. When sharing the information, or processing it, people make mistakes. They make less mistakes and even much less when using the correct procedures for obtaining information described above, but they still make mistakes. Therefore, the information received from the person must be exposed for verification, and not used uncontrollably.

Closed procedures are very effective remedies in which previously obtained information is verified indirectly rather than directly. The survey procedure is structured so that the questions are duplicated, but this duplication is carried out implicitly, through other questions that are logically related to the first ones.

Let's take a simple example. Suppose we want to streamline four variables according to their value: A, B, C, D. Pairwise comparison of each variable with each one allows us to obtain the redundancies necessary to check for consistency.

The methods of verbal decision analysis provide for:

- checking the information of the decision-maker for consistency,
- presentation of contradictory information of the decision-maker,
- methods of analysis and elimination of contradictions.

6.4. The practical value of the approach of verbal decision analysis

In practice, the approach to verbal decision analysis (the VDA) methods has significant advantages over axiomatic and heuristic methods. When compared with heuristic methods, it is possible to state that all procedures for obtaining information from a decision-maker are psychologically reasonable. All transformations of the data have a mathematical foundation. The popular features of human behavior in organizations when making decisions are taken into account: the possibility of step-by-step development of a definitive rule. The approach to VDA methods are "invisible" for the decision-maker: he gives answers to many questions of the computer posed in his natural language; he can check if the recommendations match his preferences.

A comparison of axiomatic methods and approach to the VDA methods were carried out in laboratory experiments (Larichev, Olson *et al.*, 1995) and on real tasks (Flanders *et al.*, 1998).

The experimental group (students of one of the American universities) solved the problem of choosing a place of work by three methods. A comparison of the axiomatic approach with the approach of VDA was also carried out on real problems of choosing the methods of transporting oil and gas in the Arctic. The comparison showed the strengths and weaknesses of each approach. However, according to most of the criteria, the VDA approach turned out to be preferable. Moreover, the experiment showed the unreliability of axiomatic methods, their sensitivity to decision-makers' errors.

The approximate measures of the recommendations were recognized as the drawbacks of the VDA, since the alternatives may not be comparable. However, results, obtained using this approach, reliably reflect the preferences of the decision-maker. The apparent accuracy of axiomatic and heuristic methods very often leads to errors when comparing alternatives (Larichev, Olson *et al.*, 1995).

The VDA group methods. Traditionally, it is customary to distinguish three main tasks of decision making.

1. **Oredring the alternatives:**

For several tasks, the requirement to determine the streamlining of the set of alternatives seems to be quite reasonable. For example, family members arrange future purchases according to the degree of necessity; company leaders arrange investment objects according to profitability, etc. In general, the requirement for streamlining the alternatives means that we want to determine the relative value of each of the alternatives.

To solve this task, in the group of methods of VDA, the ZAPROS method (Closed Procedures for Supporting Situations) was developed (Larichev, Moshkovich, 1996; Larichev, Zuev *et al.,* 1974), UniComBOS (Ashikhmin, Furems *et al.,* 2003, Ustinovičius, Shevchenko *et al.*, 2010). It allows you to build a rule for ordering multi-criteria alternatives based on the preferences of the decision-maker. It is required to determine a set of criteria and their scales that describe the area under consideration to create a rule. The constructed decision rule allows you to compare any two alternatives described by the entered criteria.

2. **Distribution of alternatives by classes of solutions:**

Such tasks are common in everyday life. So, people usually divide the alternatives into two groups when buying or exchanging an apartment or a house: deserving and not deserving more specific, requiring the expenditure of effort and measures of research. Product groups vary in quality. The applicant is divided into groups of universities in which he aspires to enter. Precisely how people often identify groups of books for themselves (by attractiveness for reading), hiking trails, etc.

The classification of alternatives can be used to build expert knowledge bases in certain areas, for example, diagnostics (assignment to one of the classes) of a patient's clinical picture, described by a set of symptoms (assessments) according to several clinical signs (criteria).

Several methods have been developed to classify alternatives within the VDA approach. The first such method was ORKLASS (ordinary classification) (Larichev, Moshkovich 1996), which makes it possible to organize a complete set of alternatives (all possible alternatives described by a given set of criteria and their scales). Later, the CYCLE (sequential interactive classification) method was developed (Asanov, Borisenkov *et al.,* 2001), which allows us to solve the same problem faster. Another method is CLARA (Classification of Real Alternatives) (Kochin, Larichev *et al.*, 2002; Ustinovičius, Barvidas *et al.,* 2011; Shevchenko, G.; Ustinovichius *et al.,* 2011; Ustinovichius, Shevchenko *et al.,* 2007) allows building a classification of not only the complete set of alternatives but also a given subset.

3. **Highlighting the best alternative.**

This task traditionally has been considered one of the most basic in decision making, often found in practice. Choosing one item when buying, choosing a place of work, selecting a project for a sophisticated technical device – these examples are well known. Besides, such tasks are common in the world of political decisions, where there are relatively few alternatives, but they are quite challenging to study and compare. For example, you need a better way to exchange money, a better way to carry out land reform, etc. The construction of new alternatives in the process of problem-solving is a common feature of many political decision-making tasks.

This problem is solved by the methods PARK (Pair Compensation) (Larichev, Moshkovich, 1996) and SNOD (Scale of Normalized Ordered Differences) (Kochin, Larichevetal. 2003; Ustinovichius, Kochin, 2003; Ustinovichius, Kututetal 2008; Ustinovičius *et al.,* 2011). SNOD is a more modern method, and it allows you to work with a large number of criteria and alternatives, unlike PARK.

These methods are summarized in Table 6.2.

Another interesting application of expert classification methods is worth mentioning. The constructed knowledge base can be not only consulting, meaning, being an oracle, referring the presented alternative to one of the solution classes. The beginners can be taught expertise using human implicit learning capabilities. Working systems for teaching medical diagnostics of several diseases were built (Larichev, Naryzhny 1999; Ustinovičius *et al.,* 2005; Kochin *et al.,* 2005).

TABLE 6.2. Some methods of verbal decision analysis.

ZAPROS (Larichev, Moshkovich 1996; Larichev, Zuev *et al.*, 1974); UniComBOS (Ashikhmin, Furems *et al.*, 2003; Ustinovičius, Shevchenko *et al.*, 2010)	Ranking the full set of alternatives
PARK (Larichev, Moshkovich 1996)	Finding the best alternative from the given
SNOD (Kochin, Larichev *et al.*, 2003; Ustinovichius, Kochin 2003)	Search for the best alternative from the given ones (allows you to work with more criteria and alternatives than PARK)
ORCLASS (Larichev, Moshkovich 1996)	Expert classification of a complete set of alternatives
CLARA (Kochin, Larichev *et al.*, 2002; Ustinovičius, A. Barvidas *et al.*, 2011)	Expert classification of a given set of alternatives
CYCLE (Asanov, Borisenkov *et al.*, 2001)	Expert classification of the full set of alternatives (faster than ORCLASS)

There are many different decision-making problems in the real world. Many normative methods were previously proposed as a universal measure of solving all issues. Now is the time for detailed classifications of both problems and methods.

In our opinion, methods of verbal decision analysis have significant advantages over other methods concerning problems with the following characteristics:

1. there are no reliable quantitative methods for measuring criterion assessments. Estimates can only be obtained from people (experts);
2. there are no reliable statistics that would allow to select objectively the best rules for assessing the quality of alternatives. The decision rule can only be constructed based on the subjective preferences of the decision-maker.

6.5. Best alternative determination by SNOD method

In many cases, the exclusion of the dominant alternative in a pair when choosing the best alternative is used by pairwise comparison of alternatives methods. First of all, this approach is typical for people making choices in everyday life without using computers. O. Svenson and G. Montgomery proposed a psychological theory of the search for a dominant structure, which has a descriptive character (Montgomery, Svenson, 1989). According to this theory, the Decision-Maker (DM) wants to find the best alternative by pairwise comparison of alternatives method, which would be superior to each of the others. Following the theory of the search for a dominant structure, the decision-maker "looks at" all the given alternatives and chooses from the one that (according to the first impression) could be dominant. Then he compares the chosen one to all the others in pairs. If in all comparisons, the chosen alternative wins, then the dominant structure is built. If in some comparison, a different alternative turns out to be the best, then it is already considered as potentially dominant, and all others are compared with it.

Thus, to implement such a scheme, the following operations must be performed:
1. choosing the first approximation of the best alternative – the Potentially Best Alternative (PBA);
2. comparing the PBA with each of the other alternatives.

Both of these operations are quite difficult for humans. Thus, when identifying a specific subset of the best alternatives, subjects can remove the dominant alternatives and leave the dominated ones (Korhonen, Larichev *et al.,* 1997; Ustinovičius, Kochin 2003). With the selection of the best alternative in a pair, a person confidently copes only with a small number of alternatives.

The method for choosing the best from the group of alternatives presented below, the SNOD method, facilitates the decision-maker task as follows.
1. he conducts pairwise comparisons of all alternatives according to specific rules, actively using the capabilities of a computer, without the participation of a decision-maker, choosing a PBA;
2. the method facilitates substantially further pairwise comparison of alternatives by breaking the multicriteria comparison into a series of low-dimensionality comparisons (illustrated in Figure 6.1.). On the left there are two compared multicriteria alternatives. Criteria scores are presented as horizontal bars. If for a given pair of alternatives, it is possible to split the set of criteria into small subgroups, so that one alternative turns out to be better than the other for any such subset (the estimates provided for all different subgroups are the same), then we can conclude that this alternative is generally better than the other. The task of the method is to find such a division of the criteria into subgroups.

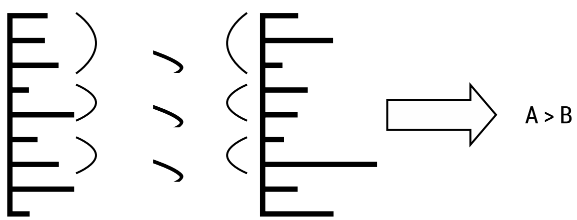


FIGURE 6.1. Comparison of multicriteria alternatives

The method consists of two main stages:
1. a formal analysis of a group of alternatives. The computer entirely performs this stage. At this stage, the PBA is selected, and the priority of questions for the decision-maker is prepared;
2. a dialogue with a decision-maker. At this stage, multicriteria comparisons are made, and a series of pairs of low-dimensional alternatives are presented to the decision-maker for comparison.

A practical example. Here is a practical task, by the example of which we will demonstrate the application and structure of the method. For clarity, we will restrict ourselves to a small number of alternatives, although the considered method can work with a large number of them.

The firm is looking for a site to build a large department store. A preliminary analysis showed that there are four possible building locations (Var 1 – Var 4). When solving the problem of selection, the board of the company decided to be guided by the following criteria (Ustinovicius, Jakučionis, 2000): the price of a place, population density within a radius of 1 km, presence of the competitors, communications infrastructure, number of parking spaces, availability of an area using public transport and visibility of the store from the nearest main street.

Experts evaluated the options outlined in advance, and either scale of assessments in natural units or verbal evaluations were used. Options with estimates are presented below in table 6.3. The table shows the desired direction of change in estimates for each of the criteria (max or min).

TABLE 6.3. Options for a place to build a store

	Var 1	Var 2	Var 3	Var 4
Number of parking spaces, max	400	300	250	150
The presence of competitors, min	1 Few	5 Alot	3 Medium	5 Alot
Population density within a radius of 1 km, max	200	4500	6000	7000
Seat price, million litas, min	6	16	12	20
Public transport flow, max	1 Low	3 Medium	5 High	7 Very high
Visibility from the main street, max	5 Good	5 Good	3 Medium	1 Bad
Communication infrastructure, max	3 Medium	3 Medium	5 Good	Very good

6.5.1. Formal statement of the problem

The given:

1. C_i – multi-criteria, i =1,.,q,..N.
2. $C = C^{\uparrow} \cup C^{\downarrow}$, where $C^{\uparrow}$ are the criteria evaluations, for which the maximum value is desirable, and $C^{\downarrow}$ vice versa;
3. s_q number of evaluations on the q-criterion scale;
4. $X_q = x_i^q$ – high number of evaluations on the q-criterion scale; $|X_q| = s_q$;
5. $Y = X_1 \cdot X_2 \cdot \ldots X_N$ – high number of vectors $y_i \in Y$ type: $y_i = (x_1^i, x_2^i, \ldots x_N^i)$, where $x_i^q \in X_q X_q$ and $P = |Y|$.

6. $V(y_i)$ – the total value of the alternative for the decision-maker. It is assumed that it has the following properties: a) there is a maximum and minimum value on the set *Y*; b) the value increases with the improvement of the assessment for each of the criteria at independent criteria $V(y_i)$,
7. $A = \{a_i\} \in Y$; $i = 1, 2, ..., n$ a set of *n* vectors describing real alternatives.

It is required to choose the best alternative from the set A corresponding to the most significant value of the a priori unknown function, based on the preferences of the decision-maker (DM).

6.5.2. Assumptions

The method is based on the following assumptions about the capabilities of the decision-maker:

1. the decision-maker can compare two multicriteria alternatives in terms of preference that differ in their values only on two criteria;
2. the decision-maker can compare two alternatives in terms of preference that differ in the number (more than two) of criteria if, in this case, one alternative is preferable to the other in one criterion and is inferior to it in no more than three criteria.

In pairwise comparisons, the decision-maker can give one of three possible answers:

1. alternative A is preferable to alternative B;
2. alternative B is preferable to alternative A;
3. alternatives A and B are equally preferred.

The assumptions made about the possibilities of the decision-maker have the following justifications:

- The first assumption was tested repeatedly when applying the methods of the ZAPROS system (Larichev, Moshkovich, 1996; Ashikhmin *et al.,* 2006). It turned out that people are entirely consistent and coherent in performing this operation. The experiments showed 2-6 contradictions of 50-60 comparisons.
- The second assumption was tested in the work (Furems, Foizenson, 2002). It is assumed that, at the independence of the criteria, comparing the preferred value of one alternative with two or three preferred values of the other alternative does not create an undue load on short-term memory. The hypothesis of the decision-maker capable to consistently and coherently compare objects that differ in assessments by three criteria was confirmed.

Based on these assumptions, a procedure is proposed for pairwise comparison of two multicriteria alternatives based on the principle of pair compensation, when the disadvantages of one alternative are trying to balance the weaknesses of the other and, as a result, it is determined which of the two alternatives has fewer disadvantages (or more advantages).

6.5.3. Formal analysis

The main goal of a formal analysis of a set of alternatives is to identify a potentially best alternative (PBA), which sort of is a reference for decision-makers when compared in pairs with other alternatives. The PBA search is carried out based on the de Condorcet principle (Guibo 1973; Ustinovichius, Kochin, 2008): "the alternative that wins with the largest number of pairwise comparisons is the best." Thus, at the stage of formal analysis, all pairs of alternatives are compared.

Of course, at the stage of formal analysis, we still do not know anything about the preferences of the decision-maker about the importance of specific evaluations by criteria for him. However, even under these conditions, formal analysis can focus the decision-makers' attention on an alternative, which surpasses the others.

Computer analysis of the problem is carried out without the participation of the decision-maker. The analysis assumes equal importance of the criteria. The formal analysis consists of two stages:

The first stage is aiming at a pairwise comparison of all alternatives, performed by a computer according to the following algorithm:

1. The estimates of alternatives are normalized in each pair of compared alternatives:

a) for qualitative scales: qualitative assessments are converted into points (serial number of the qualitative evaluation on the scale): $a_k^q := i \mid a_k = x_i^q$

b) for all quantitative and converted qualitative scales the average of the ratings of the two alternatives are found $a_{ij}^q = \dfrac{a_i^q + a_j^q}{2}$;

c) the assessment of the alternative is divided by the average; if the criterion requires min, then the quotient is subtracted from 2:

$$\left|a_i^q\right|_{ij} = \begin{cases} \dfrac{a_i^q}{\overline{a}_{ij}^q}, \ C_q \in C^{\uparrow} \\ 2 - \dfrac{a_i^q}{\overline{a}_{ij}^q}, \ C_q \in C^{\downarrow} \end{cases} \quad \text{and} \quad \left|a_j^q\right|_{ij} = \begin{cases} \dfrac{a_j^q}{\overline{a}_{ij}^q}, \ C_q \in C^{\uparrow} \\ 2 - \dfrac{a_i^q}{\overline{a}_{ij}^q}, \ C_q \in C^{\downarrow} \end{cases}.$$

2. For each of the two alternatives, the total of the points obtained in this way is calculated, the winner is the alternative with the highest total.

Let's take a closer look at normalization. This form of normalization limits the normalized values in the range [0, 2] and preserves the relationship between the scores for one criterion. The normalization process assumes that the criteria scales are positive, starting at zero. If the scale for one of the criteria contains both positive and negative values, then the criterion should be revised to apply the method.

Qualitative values can be translated into scores in many different ways. However, the reduced form of normalization allows you to evenly distribute the qualitative values in the interval [0, 2], which is quite natural.

Finally, we note that the presented normalization algorithm can be applied to a group of alternatives. However, the best alternative in the group may differ from the best alternative obtained based on the de Condorcet principle.

The second stage consists of preparation for a sequence of an interview of decision-maker to identify his preferences.

This stage is also performed by a computer without the participation of a decision-maker.

a) An alternative is selected based on the de Condorcet principle (Guibo 1973), which wins the most in pairwise comparisons at the first stage. It is declared as the potentially best (PBA);
b) All alternatives that are not Pareto optimal are excluded from consideration;
c) The rest of the alternatives are ordered according to the magnitude of the formal difference from the PBA: from large (more obvious superiority) to small, to ensure a gradual increase in the difficulty of comparisons for decision-maker.

So, the purpose of a formal analysis is to prepare a set of questions for decision-maker, which allows:

- to provide a minimum workload for decision-maker, the least expected number of questions;
- to provide a gradual increase in the difficulty of the questions;
- to ensure the maximum possible use of information from the decision-maker.

6.5.4. Cycles in the phase of formal analysis

Determining the potentially best alternative through pairwise comparisons at the stage of formal analysis, we use the de Condorcet principle (Guibo, 1973; Ustinovichius, Kochin 2008): "The best alternative is considered, which wins all others in pairwise comparisons".

Although de Condorcet principle seems to be indisputable when assessing the paired comparisons, in some cases, it leads to cyclicity on a set of alternatives. For example, consider the following three alternatives A, B, and C:

	A	B	C
Criterion 1, max	1	2	3
Criterion 2, max	2	3	1
Criterion 3, max	3	1	2

According to the results of formal analysis, it turns out that B A, A C, but B C.

In general, cycles can occur, an algorithm for searching for PBA is needed. The following algorithm is most reasonable. If the alternatives A_i, A_j, and $A_k$surpass all others in pairwise comparisons and at the same time form a cycle, then as the PBA, one should take the alternative that is better in the group comparison of A_i, A_j, and A_k. If they all turn out to be of equal value, then any of them can be taken as a PBA.

Example: The formal analysis. Table 6.4 contains the results of the precise comparison of Var 1 and Var 2. It shows the initial alternatives, normalized according to the rules of formal analysis of the value, the vector difference between the options (the "Difference" line), and the result – the sum of the "difference" components. If the result is greater than 0, then the first alternative of the pair is better than the second, otherwise – vice versa.

TABLE 6.4. An example of comparison at the stage of formal analysis

Criterion	1(max)	2(min)	3(max)	4(min)	5(max)	6(max)	7(max)
Comparison of Var 1 and Var 2							
Var 1	400.00	1.00	200.00	6.00	1.00	5.00	3.00
Var 2	300.00	5.00	4500.00	16.00	3.00	5.00	3.00
Normalized Var 1	1.14	1.67	0.09	1.45	0.50	1.00	1.00
Normalized Var 2	0.86	0.33	1.91	0.55	1.50	1.00	1.00
Difference:	0.29	1.34	-1.83	0.90	-1.00	0.00	0.00
The result: -0.30; Var 2 is better than Var 1							

In this case, alternative Var 2 turned out to be the best of the pair. Comparing the other pairs of alternatives in a similar way, we obtain the results of paired comparisons (Table 6.5):

TABLE 6.5. Pairwise comparison results.

Alternative	Number of the paired comparisons won
Var 1	1
Var 2	2
Var 3	**3**
Var 4	0

Thus, the potentially best alternative is Var 3, which is the best for all pairwise comparisons.

Dialogue. DM-DSS. Revealing the preferences of the decision-maker is carried out on comparisons relating to the pairs of alternatives presented to him sequentially, starting with the pairs in which the PBA is presumably superior.

The dialogue can be divided into two stages.

Stage 1: Prepare comparisons. At this stage, the decision-maker reviews the assessments of all alternatives presented to him and answers the following questions:

1. "Are there any alternatives that differ little from each other, and can be considered as almost the same, when compared in pairs?" Combining close values will reduce the number of questions to decision-makers.
2. "Are there any alternatives among the assessments that characterize an unacceptably low quality according to this criterion, which makes it possible to exclude the alternative from consideration immediately?". The exclusion of alternatives with an uncompensated disadvantage, that is, such a disadvantage in which even the most preferable estimates by other criteria cannot make it the best, will also reduce the number of questions to the decision-maker.

The computer helps make questions 1 and 2 more specific.

When preparing the first question, all alternatives are harmonized (see formal analysis) and are presented for decision-makers for the consideration of a pair of assessments. The normalized values of the assessments differ by no more than 0.1÷0.15, or two adjacent quality statements on the scale of a qualitative criterion (if they belong to the compared alternatives).

Setting the second question, the estimates of alternatives are shown, the normalized values of which do not exceed 0.1÷0.15 from the estimates of other alternatives. The assessments of alternatives on the criteria scales remaining after stage 1 are **compensable**. Indeed, leaving these estimates, the decision-maker admits the possibility of compensating for the comparative disadvantages of the alternative with its advantages.

Stage 2. Pairwise comparisons of alternatives. At this stage, the decision-maker makes pairwise comparisons of the alternatives remaining after stage 1 with the PBA. At the same time, an effort dividing the set of criteria into groups of 2-4 is made in a way for the first of the alternatives to be better than the second for each such group.

Normalization is performed for each compared pair of alternatives, and the criteria are sorted in descending order of the formal superiority of the PBA in the pair. For example, consider an example comparing Var 1 and Var 2 (Table 3). Let's sort the criteria by nonzero values from the "Difference" line. We put the ordered criteria on a special scale, as shown in Figure 6.2.

On the left of the scale, there are advantages of Var 1, on the right – disadvantages, or the advantages of Var 2. The method offers the decision-maker to compare the advantages and disadvantages, starting from the ends of the scale towards its center, that is, the (presumably) more significant advantages and disadvantages are compared first. If one disadvantage (advantage) is missing to compensate for the advantage (disadvantage), then the method adds another one following the previous one. For example, let's assume that in this case, the decision-maker answered that the advantage means more to him according to criterion 2 than the disadvantage according to criterion 3 (marked with a sign ⌒). Further, the method will ask the decision-maker to compare the advantage according to criterion 2 with two disadvantages, according to criteria 3 and 5. If, in this case, the advantage is not enough to cover the disadvantages, then the advantage according to criterion 4 and the disadvantage, according to criterion 5, will be compared further. Let the advantage, according to criterion 4, be equivalent disadvantages according to criterion 5 (marked with a sign ⌒⌒). As a result, Var 1 has one uncompensated advantage in criterion 1, which allows us to conclude that Var 1 wins the comparison.

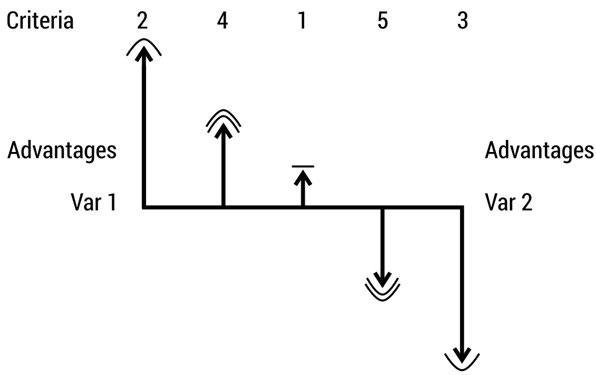


FIGURE 6.2. The Scale of Normalized Ordered Differences (SNOD)

Let's note that according to the results of the formal comparison, Var 2 was better than Var 1. However, the comparisons made by the decision-maker showed the opposite. This may well happen since the normalization process does not take into account the weights of the criteria. At the same time, the decision-maker makes comparisons, always having in mind the importance of the criteria (in a qualitative form). Moreover, the decision-maker always knows a little more about the problem than it can be formalized and uses all this knowledge in the comparison process.

So, the comparisons carried out by the decision-maker are based on the use of a particular type of scale. This scale shows the relative differences (in the sense of the normalization used) between the two alternatives, in terms of criteria, ranging from the advantages of PBA, and ending with its disadvantages. Let us note the features of this scale. It:

1. is built for a pair of alternatives;
2. is relative, not absolute;
3. is ranked according to the formal differences of alternatives, and not according to the preferences of the decision-maker.

This scale can be used as a tool for making comparisons of decision-makers for selecting questions. The method based on the use of this scale will be called the SNOD method (Scale of Normalized Ordered Differences).

6.5.5. Possible criteria dependency

If the criteria are dependent, the decision-maker cannot conclude about the preference of one or another alternative from the pair, considering only a part of its criteria, even taking into account the fact that the estimates for the other criteria are the same. In this case, the decision-maker needs to know these values. That is, the comparison of the advantages and disadvantages of the two alternatives should take place against a certain "background" of assessments by the remaining criteria. Moreover, the result of comparing alternatives may depend on the choice of this background.

Since our method compares predetermined alternatives, to exclude the influence of the dependence of the criteria on the comparison result, it is proposed to compare twice: firstly, against the background of the first alternative in a pair, and then, a check comparison against the background of the other. If the results of both comparisons coincide, it can be concluded that the possible dependence of the criteria did not affect the outcome. Otherwise, one cannot find which of the alternatives is superior.

In cases when it cannot be concluded from the results of comparisons which alternative is the best, the alternatives are considered incomparable based on the decision-maker's information.

Example: The decision-maker survey. The first step is to combine close values (Figure 6.3). On the computer screen, alternatives with similar criteria are presented, which are highlighted in color. In our example, the program advises the decision-maker to pay attention to close estimates of 250 and 300 for the first criterion.

If the values are equally preferable for decision-makers, then they can be combined and replaced by the average value. This will reduce the number of questions asked.

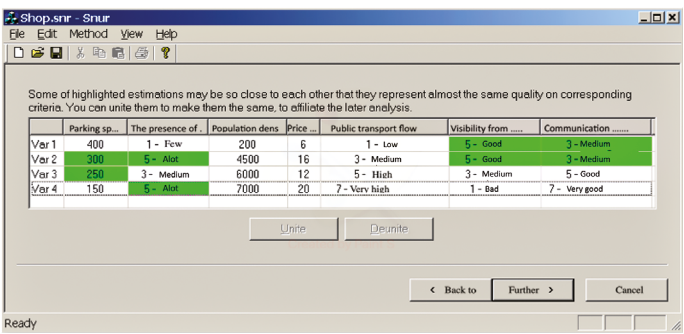


FIGURE 6.3. Consolidation of close values

The second step is to exclude alternatives with low uncompensated values (Figure 6.4). The program highlights the values with little importance in color. In this example, the program notices a deficient value according to the criterion “Population density” of variant Var 1. If this value is unacceptably low in the opinion of the decision-maker, then it can be excluded from consideration.

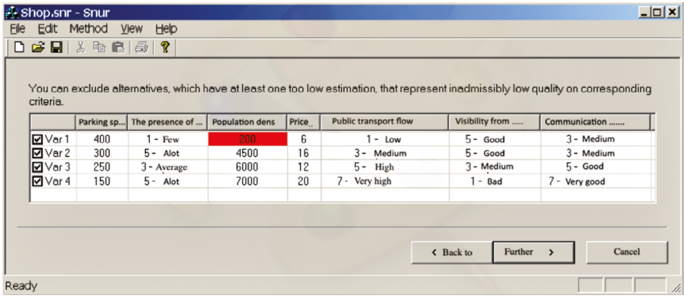


FIGURE 6.4. **Exclusion of alternatives with unacceptably low values**

The third step is to compare pairs of alternatives (Figure 6.5). Before this step, the program determines the sequence of questions to be asked. The decision-maker may be asked to compare one disadvantage of one alternative with one or several advantages of another against the background of the first one alternative, then another.

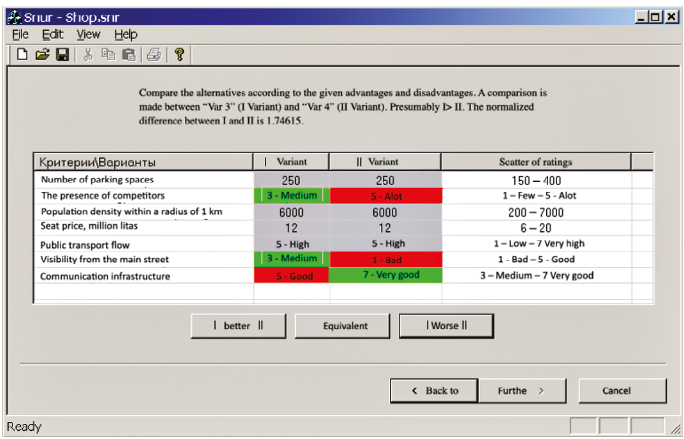


FIGURE 6.5. **Comparison of alternatives**

When the questions to the decision-maker are asked, the comparison results are presented on the computer screen (Figure 6.6). In the example, it took ten questions for the decision-maker to establish the superiority of Var 3 over others. Alternative Var 1 was excluded from consideration due to its low value for the criterion “Population density within a radius of 1 km”.

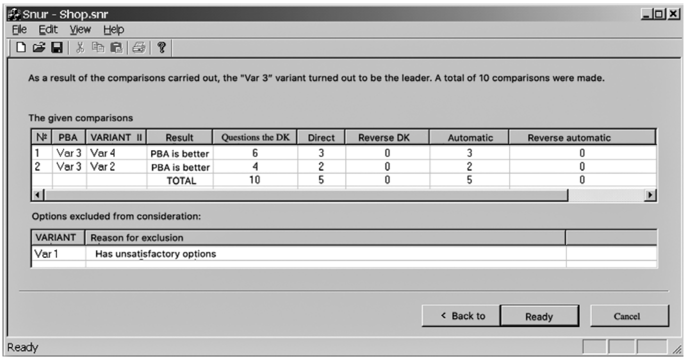


FIGURE 6.6. Comparison results

Checking the consistency of the decision-maker's preferences. When accessing the information from the decision-maker, this information is inspected for consistency. It is being implemented in two stages.

1. At the stage of comparisons of the decision-maker.

All comparisons related to each pair of criteria are checked for consistency. If there are contradictory comparisons, then it is checked for the dependence reasons of the criteria, taken into account by the decision-maker when making comparisons. If a contradiction is found, the contradictory comparisons are presented to the decision-maker for analysis and elimination of contradictions.

2. At the stage of comparing alternatives.

The review is being actioned through fixing all pairwise comparisons carried out by the decision-maker. When identifying cycles on a set of pairwise comparisons of alternatives, included in the cycle, presented by the decision-maker, with a request to revise some of them necessary to remove the cycle.

Getting recommendations. The SNOD method helps the decision-maker to choose the best alternative in many cases. However, it does not always lead to this result; the alternatives may be incomparable.

In this case, the method gives the decision-maker the following information:

1. Indicates the best alternative allegedly with the highest sum of normalized estimates;
2. Informs about another alternative, which is very close to the best, gives estimates of these alternatives;
3. Proposes to introduce additional criteria by which one can distinguish between incomparable (by method) alternatives;
4. Submits the final choice at the discretion of the decision-maker.

6.5.6. Statistical modeling

In the above method, the central place is occupied by the comparison of two multicriteria alternatives using the SNOD. It is reasonable to question how effective the comparison is, meaning by, how many questions the decision-maker is asked, and how often incomparability of alternatives can arise.

The comparison of alternatives is an attempt to cover the disadvantages of an alternative with its advantages. To illustrate this statement, refer to Figure 3. Supposing the length of the vertical arrows (advantages and disadvantages) mean their value to the decision-maker. Then covering disadvantages by advantages means covering negative indicators (disadvantages) with positive (advantages) as shown in Figure 6.7.

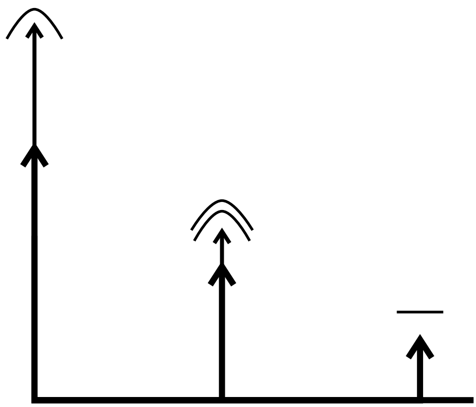


FIGURE. 6.7 Covering

Optimally, such an encloser can be constructed using an exhaustive search algorithm. However, the main difficulty is not to know in advance how to compare the length of the arrows (that is, the values of advantage and disadvantage). The decision-maker must be asked a question to compare them. And the exhaustive search algorithm may require a large number of comparisons.

The construction of the covering using the SNOD method is carried out at a linear speed (that is, the number of questions for the decision-maker grows linearly with the number of advantages and disadvantages in a pair of alternatives). Still, due to this, it is possible to find covering less often.

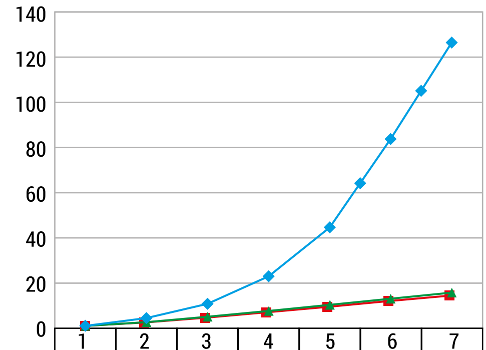
Besides, the advantages and disadvantages are ordered by a regular feature, on the scale of differences, and not by their value to decision-makers, which can also impact the effectiveness of finding coveraging.

For a quantitative evaluation of the above arguments, statistical modeling was carried out. A straightforward model that implements the value function $V(y) = y$ was used as a model for the decision-maker. In other words, the length of the arrows was taken as the actual value for the decision-maker.

A scale of differences with the same number from 1 to 7 of the advantages and disadvantages was randomly generated 10,000 times. Further, the comparison was carried out using three algorithms:

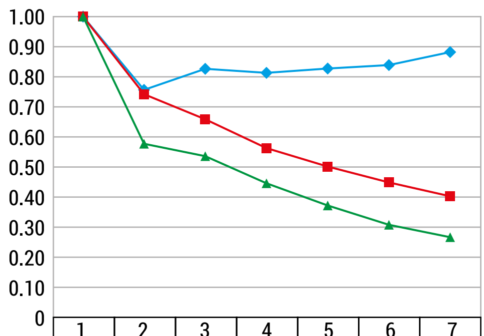
1. The algorithm for an exhaustive search for constructing coverage (Search);
2. The SNOD algorithm with a unsordered scale (SND);
3. The SNOD algorithm of ordered scale (SNOD).

For each case, the number of questions asked by the decision-maker and the result of comparison (comparable or incomparable) were recorded. The results are 7x7 tables, where for each pair <number of advantages, number of disadvantages> the average number of questions to the decision maker and the percentage of comparable alternatives are written. However, for reasons of convenience and clarity, we present here only the results for comparisons with the same number of advantages and disadvantages (Figure 6.8, Figure 6.9).



	1	2	3	4	5	6	7
SEARCH	1.00	4.45	10.79	23.04	44.66	83.71	126.30
SNOD	1.00	2.50	4.67	7.07	9.50	11.93	14.32
SND	1.00	2.67	5.03	7.61	10.27	12.98	15.71

FIGURE 6.8. Number of questions for decision-maker



	1	2	3	4	5	6	7
SEARCH	1.00	0.76	0.83	0.81	0.83	0.84	0.88
SNOD	1.00	0.74	0.66	0.56	0.50	0.45	0.40
SND	1.00	0.58	0.54	0.45	0.37	0.31	0.27

FIGURE 6.9. Rate of comparable alternatives

The X-axis in the figures shows the number of advantages and disadvantages in the compared pair of alternatives. As can be seen, in the case of the exhaustive search algorithm, the number of questions for decision-makers is vast and grows exponentially with the growth of the dimension of alternatives. In the algorithms SNOD and SND, the number of questions is asked, which linearly depends on the aspect, which makes it possible to use them in real life.

The part of comparable alternatives for the exhaustive search algorithm is maximum and cannot be surpassed by any other algorithm. The figure shows that the part is quite high and ranges from 0.8 to 0.9. Algorithms SNOD and SND show less efficiency: the share of comparable alternatives for them decreases with increasing dimension and range from 0.4 to 0.8 for SNOD and 0.3 ÷ 0.6 for SND. The differences are ordered under the formal profile of real applications of the SNOD algorithm, which often does not meet the opinion of the decision-maker, but only correlates with it. Therefore, the actual share of comparable alternatives for the SNOD algorithm will lie somewhere between the curves of the SNOD and the SND.

In conclusion, it can be noted that the efficiency of the SNOD method can be increased by using a more sophisticated algorithm for constructing a covering (for example, an exhaustive search algorithm) in the case of incomparability of alternatives, which, can resolve it by a more significant number of questions.

The SNOD method for choosing the best of given alternatives from the group has the following features:

1. The method uses rather simple (from the psycho1ogica1 point of view) procedures for the e1icitation of preferences of the decision-maker;
2. The dialogue language is suitable for the decision-maker, suing the quantitative and qualitative estimates of the criteria of the alternatives;
3. The method enables one to compare a large number of alternatives by using the minimum amount of questions for the decision-maker;
4. The method can quickly adapt to a specific task (set of alternatives) and always resu1ts in the best (or presumably best) alternative;
5. The method provides an opportunity for the decision-maker to receive explanations of the results by displaying those of his answers, which have led to the obtained result.

The SNOD method is convenient for the decision-maker, “transparent” and effective method for the solution of a great variety of tasks

6.6. Selecting a subset of the best alternatives by UniComBOS method

6.6.1. Appointment of the method

The UniComBOS method (Combination of Paired Comparisons) is designed to solve a wide range of individual multicriteria choice problems related to the selection of a subset of the best alternatives (options, objects, methods of action, strategies). The UniComBOS method belongs to the group of methods of verbal decision analysis (VDA).

The selection task has the following features. There is a finite set of alternatives characterized by many quantitative (numerical) or qualitative (verbal) features. Often, alternatives can only be obtained through a complex creative process involving experts from various fields of knowledge. The decision-maker needs to select the best alternatives from the many available. The decision-maker is guided by the desire to achieve some goals, often contradictory when choosing the best alternative. Criteria are used to reflect the extent to which these objectives have been completed. The criteria are the most significant characteristics of alternatives for the decision-maker, so he must form a list of them.

On the one hand, the more aspects of the task are reflected in the criteria list, and the more reasonable the choice will be. On the other hand, too many criteria can significantly complicate the option for the decision-maker. There can be several different sets of criteria that describe the same set of alternatives equally well. When starting to solve a new task, the decision-maker is not always able to formulate exhaustively all aspects that are significant for him. Therefore, the UniComBOS method provides that the decision-maker can supplement the set of criteria at any time. In this case, the previously obtained information about the preferences of the decision-maker will, if possible, be used in the problem with an extended structure.

Another essential feature of the UniComBOS method is when the rating scale for each criterion is not set in advance but is formed from all real assessments of the viable alternatives for this criterion, which distinguishes it from many other methods of multi-criteria decision-making, including all previously developed methods of verbal decision analysis.

Based on his preferences and using a multicriteria representation of alternatives, the decision-maker seeks to narrow the initial set to a set of the most preferred non-dominated options that suit him, ideally consisting of one best alternative. The main idea of the method is as follows.

Particular sets of estimates of the vector are constructed to identify the preferences of the decision-maker. Each set has a fixed subset of criteria, and the vector estimates contain real values for these criteria. Pairs of vector estimates belonging to the same set are sequentially presented by the decision-maker for comparison, starting with the simplest ones – single-criterion, with a further increase in the number of real estimates.

The decision-maker determines the equivalence or preference for one of the estimates of the vector when comparing them. Based on the results of such comparisons, a sequential narrowing of the initial set of solution options is made. The essence of the method lies in the fact that the obtained information when comparing "simple" combinations of estimates can be used to distinguish "complex" combinations, descriptions of real alternatives, in particular, which makes it possible to obtain many non-dominated alternatives quickly. In several cases, after such a check, it is possible immediately to find a solution to the original problem of choosing the best real alternative, which satisfies the decision-maker, without performing further comparisons. This is another essential feature of the UniComBOS method.

The UniComBOS method provides individual reviews of the answers of the decision-makers for consistency, which are performed after each comparison of vector estimates. To reduce the number of comparisons of vector estimates, a particular procedure to select the next pair of vector estimates presented by the decision-maker for comparison is performed. The process is based on solving an optimization problem of integer linear programming. The order of presentation of pairs of vector estimates for comparison is formed based on the results of the procedure.

Predicting the behavior of the decision-maker can significantly reduce the number of requests to the decision-maker, and substantially reduces the labor-intensity of the method for a person. Besides, it is possible to adjust to the individual abilities of a particular person based on how he compares vector estimates and to adapt the procedure of interviewing the decision-maker to his cognitive characteristics. This customizability of the UniComBOS method to the individual is its salient feature.

And finally, like other methods of verbal decision analysis, the UniComBOS method provides the opportunity to obtain an explanation of the intermediate and final results obtained using the comparisons of vector estimates performed by the decision-maker.

The UniComBOS method includes the following steps:

1. Structuring the problem;
2. Revealing the preferences of the decision-maker;
3. Checking the preferences of the decision-maker for consistency;
4. Comparison of vector assessments of real alternatives in terms of preference;
5. Choice of a subset of maximal (non-dominated) alternatives.

Let us have a more detailed discussion about the stages of solving the problem of identifying a subset of the best alternatives.

6.6.2. Structuring the problem

At the stage of structuring, the decision-maker must formulate the task for choice in the natural language of the corresponding problem area terms. It is necessary to list the alternatives to be chosen, to determine the criteria for their estimates, to form verbal scales of estimates for each criterion. The set of alternatives, from which it is necessary to choose the best, will be marked by the letter A.

The decision-maker singles out the characteristics of alternatives as evaluation criteria that are of interest to him. We mark the set of criteria $C = (C^1, ..., C^k)$. $K = (1, ..., k)$ – is a set of numbers of criteria. The criteria can be both quantitative and qualitative (verbal).

The estimates of the alternative A we mar a by the criterion C^j we mark by $C^j(a)$. The scale of estimates $S^j = (s_1^j, s_2^j, ..., s_m^j), j \in K$, for each criterion is not set in advance, but is formed from estimates of all real alternatives according to the selected criterion $S^j = \bigcup_{a \in A} C^j(a)$. In this case, there is no need to preorder the estimates on the scales of criteria. All possible combinations of estimates form the k – dimensional space, which is the Cartesian product of the scales of criteria $S^j = \Pi_{j=1}^{k} S^j$. Each alternative $a \in A$ is assigned corresponding the vector estimate (tuple) $C(a) = (C^1(a), C^2(a), ..., C^K(a))$, consisting of estimates $C^j(a)$ of the alternative according to criteria $C^1, ..., C^K$. Let mark through A the set $\{C(a) | a \in A\}$ vector estimates of real alternatives from the collection A. Obviously, $A \subseteq S$.

Thus, after the stage of structuring the problem, sets of alternatives A, criteria C, scales of criteria and vector estimates of A. It is required to select a subset of the best alternatives, taking into account the preferences of the decision-maker.

6.6.3. Formalizing preferences for DM

Let us introduce a new range of vector estimates, which will be needed in the future to construct procedures for revealing preferences. Let us expand the scale of each criterion S^j with a false estimate $\omega^j : Q^j = Sj \cup \{\omega^j\}$. Then the set of all possible vector estimates, including false estimates, is described by the Cartesian creations of new criteria scales $Q = \Pi_{j \in K} Q^j$, similarly to the set $S = \Pi_{j \in K} S^j$.

Let's discuss some vector estimate $x \in Q$ and a subset of criteria $J \subseteq K$. We mark the vector estimate by x^j for which the j^{th} component is equal to the j^{th} element of the vector estimate x if $j \in J$, and is equal to ω^j, if $j \in K \backslash J$. A vector estimate for which all but one of the estimates are false will be called single-criterion. If two estimates are real, then the vector estimate is called two-criteria, and so on.

The binary relations P and I are used, defined on the set of vector estimates Q to describe the preferences of the decision-maker:

$$(x, y) \in P, \text{ if } x \text{ is: preferable to } y,$$

$(x, y) \in I$, if y: x and y are equal in preference, and the binary relation $R = P \cup I$ generated by them. Moreover, for any pair of vector estimates (x,y) belonging to the binary relation P or I, if the j^{th} component of one of them is equal to a false estimate ω^j, the j^{th} component of the other vector estimate is also same ω^j.

It is assumed that the binary relations P, I, and R have the following features:

$$P \text{ – strict partial ordering (irreflexive and transitive),} \tag{6.1}$$

$$I \text{ – equivalence (reflexive, symmetric and transitive),} \tag{6.2}$$

$$R \text{ – quasi-order (transitive, reflexive),} \tag{6.3}$$

$$P \cap I = \varnothing;\ R = P \tag{6.4}$$

We assume that the criteria are mutually independent in preference in addition to the listed features.

6.6.4. DM preferences identification

Special procedures have been developed to identify preferences. The decision-maker compares vector estimates of the means of x^jf and y^j, where $J = \{j_1, j_2, ..., j\} \subseteq K$. They are presented in two rows of the table containing only real estimates (Table 6.6). The columns are named after the corresponding criteria. The estimates for the remaining criteria with numbers K\J are assumed to be arbitrary and equal in pairs. The comparison result is entered into a binary relation $\tilde{P}$ or $\tilde{I}$ as a pair of vector estimates (x^J, y^J) or (y^J, x^J) if y^J is preferable to x^J.

TABLE 6.6. **Comparison of the estimates and of the vectors**

C^{j_1}	C^{j_2}	...	C^{j_s}
x^{j_1}	x^{j_2}	...	C^{j_1}
y^{j_1}	y^{j_2}	...	C^{j_1}

Revealing preferences begins by comparing single-criterion vector estimates. The decision-maker compares the scores from the scale of each criterion in pairs. The assessments for each criterion are ordered under the preferences of the decision-maker as a result of such comparisons. Unlike other methods, where the order on the criteria scales is set at the stage of structuring, in the UniComBOS method, the order of the criteria scales appears when comparing single-criterion vector estimates. If the scale of some j^{th} criterion contains m_j scores, the m_j $(m_j - 1/2)$ comparisons will be made within this criterion.

Then a pairwise comparison of two-, three-, and so forth estimates of the criteria vector are made. An increase in the number of criteria with real estimates occurs if all possibilities of solving the problem, using the current number of criteria, have been exhausted. A particular optimization procedure is used to search for a pair of estimates of the vector presented by the decision-maker. That applies a forecasting model allowing the prediction of the decision-makers answers when he is comparing vector estimates. Pairs of estimates of vector and the sequence of their comparisons by the decision-maker are the result of the procedure for optimizing the number of referring to the decision-maker at the stage of identifying the preferences.

The preferences of the decision-maker are checked for consistency, and an attempt is made to select a subset of the best alternatives after each comparison of the estimates of the vector, including comparisons of single-criterion estimates of the vector. If a contradiction arises, its cause is determined and eliminated. This is done by presenting the decision-maker with his previous answers and the logical consequences. The decision-maker can point to an incorrect answer or express disagreement with any intermediate result. In the first case, the decision-maker corrects his response. The second case means a violation of the hypothesis about the independence of preference and/or transitivity criteria and may require a restructuring of the problem. If a contradiction is not found or it has already been eliminated, and a subset of the best alternatives has been identified, this subset is presented to the decision-maker, and the identification of preferences stops. Formulas are deduced in the first-order predicate logic using the *modusponens* inference rule to compare the arbitrary estimates of the vector. Models describing the preferences of decision-makers in the language of predicate logic are discussed in detail in Chapters 6.1-6.4.

The UniComBOS method proposes a mechanism for controlling the reliability of the information on comparisons of estimates of the vector individually for each decision-maker. An increase in the number of criteria occurs until the proportion of decision-makers' answers leading to contradictions in the total number of answers exceeds a particular predetermined threshold value, or a subset of the best alternatives is found. A large number of contradictory answers of the decision-maker, exceeding the threshold value, indicates that comparisons of estimates of the vector for the current number of criteria are too tricky for the decision-maker. Therefore, a further increase in the number of criteria will make the information obtained unreliable.

And finally, the UniComBOS method, like other methods of verbal decision analysis, provides decision-makers with the opportunity to obtain the explanation of the intermediate and final results at any stage based on the comparisons of vector estimates performed by him. The interpretation substitutes the reasoning in natural language that uses comparisons of estimates of the vector made by the decision-maker and the assumed features of his preferences. Two factors determine the validity of this reasoning:

1. The fairness of comparisons made earlier by the decision-maker;
2. The validity of the preference properties used by the decision-maker.

The decision-maker can personally control both of these factors in the content of the explanation. At the same time, he re-checks only those comparisons that are involved in the conclusion of the explained comparison. The number of such comparisons varies widely, depending on the specific problem and answers and is on the order of the number of criteria.

Thus, the validity of comparing estimates of a vector of real alternatives is determined by the validity of a given explanation based on the answers of the decision-maker himself and simple assumptions about the properties of his preferences.

As for the alternatives described by four or more criteria, reliable information on the reliability of their comparison has not yet been obtained. Therefore, the UniComBOS method proposes a mechanism determining the reliability of such information individually for each decision-maker. Thus, the preferences of the decision-maker are revealed by pairwise comparisons of alternatives that differ in estimates of one, two, three, etc. criteria.

6.6.5. Conclusion procedure

Procedures are used to prove the derivability of formulas in the logic of first-order predicates to check the revealed preferences for consistency and compare real alternatives. The features of binary relations *P, I* and *R*, and the condition for the independence of criteria by choice are rewritten in the form of first-order predicate logic formulas, for which two-place predicate $P(\boldsymbol{a},\boldsymbol{b})$ and $I(\boldsymbol{a},\boldsymbol{b})$ are introduced, meaning $(\boldsymbol{a},\boldsymbol{b}) \in \mathrm{P}$ and $(\boldsymbol{a},\boldsymbol{b}) \in I$, respectively.

The modern development of computer technology does not allow to check for the feasibility of predicate logic formulas and to maintain an interactive mode of work with decision-makers. Up to a hundred elements arise in the relations $\tilde{P}$ and $\tilde{I}$ in a task of 5-8 criteria and 4-6 alternatives. Checking the derivability of some formula $P(\boldsymbol{a},\boldsymbol{b})$, $I(\boldsymbol{a},\boldsymbol{b})$, or $P(\boldsymbol{b},\boldsymbol{a})$ using computer calculations requires time, which the decision-maker will hardly agree to spend while waiting for the next question.

A simplified reference model is used to prove the derivability of formulas in the UniComBOS method, in which the inference rule is the separation rules – modusponens. Therefore, the formulas reflecting the properties of preference relations were transformed into the form of implications. The transitivity formulas for predicates P or I were also changed so as not to take into account the values of pairwise equal estimates in pairs of vector estimates found on the left side of the implications. The comprehensive set of formulas used in the simplified model of decision-makers' preferences takes the following form:

$$I(\boldsymbol{a}, \boldsymbol{a}), \tag{6.5}$$

$$\neg P(\boldsymbol{a}, \boldsymbol{a}), \tag{6.6}$$

$$I(\mathrm{a}, b) \wedge I\,(b,a),$$

$$I(a, b) \wedge I\,(c, d)\ I(\mathrm{a}^{j}\mathrm{a}^{H}c^{G},\ d^{J}b^{H}d^{G}), \tag{6.7}$$

$$I(a, b) \wedge P\,(c, d)\ P(\mathrm{a}^{J}\mathrm{a}^{H}c^{G},\ d^{J}b^{H}d^{G}),$$

$$P(a, b) \wedge I(c, d)\ P(\mathrm{a}^{J}\mathrm{a}^{H}c^{G},\ d^{J}b^{H}d^{G}),$$

$$P(\mathrm{a}, b) \wedge P(c, d)\ P(\mathrm{a}^{J}\mathrm{a}^{H}c^{G},\ d^{J}b^{H}d^{G}). \tag{6.8}$$

Here, the vector estimates *a, b, c* and *d* are subject to the following conditions:

$$\exists J,G,H \subseteq K,\ J \cap H \cap \mathrm{G} = \varnothing,$$

$$\begin{gathered} a^{K(H \cup J)} = b^{K(H \cup J)} = \omega^{K(H \cup J)}, \\ c^{K(G \cup J)} = d^{K(G \cup J)} = \omega^{K(G \cup J)}, \\ b^{J} = c^{J} \end{gathered}$$

If, in addition to the indicated conditions for some $j \in J$ it turns out that $a^{j} = d^{j}$, then the estimates a^{j} and d^{j} on the right side of the implications are replaced by ω^{j}.

The simplified model of the decision-maker's preferences has a significantly higher clarity for explaining the results and analyzing contradictions. The withdrawal procedure is described in chapter 6.6.5.

6.6.6. Verification and elimination of contradictions

Derivability of formulas is checked only in the absence of contradictions when comparing decision-makers of various vector estimates. If the preference of the decision-maker preferences turns out to be contradictory, then the decision-maker must analyze the inconsistency that has arisen, determine its cause, and eliminate it. This is done by presenting the decision-maker with his previous answers and the logical consequences. The decision-maker can point to an incorrect answer or express disagreement with any intermediate result. In the first case, the decision-maker corrects his answer. The second case means a violation of the hypothesis about the independence of preference and/or transitivity criteria and may require a restructuring of the problem.

Checking the consistency of the decision-maker's preferences begins in the UniComBOS method as soon as the decision-maker compares more than two pairs of estimates. And after each new answer, the entire set of answers is checked for consistency.

A contradiction can arise only in the form of a violation of transitivity when comparing estimates based on one criterion. For example, the decision-maker compared the scores a^{J}, b^{J} and c^{J} according to the j^{th} criterion as follows:

- a^{j} is preferable to b^{j},
- b^{j} is preferred to c^{j},
- c^{j} is preferred to a^{j}.

This means that the estimate a^j is preferable to itself, which contradicts the condition of the irreflexivity of the relation *P*.

If such a contradiction arises, then the decision-maker presents all his comparisons and shows why the contradiction arose. The decision-maker must correct the wrong answer. If it turns out that the decision-maker does not want to change any of his answers, since they reflect his preferences in the problem being solved, then it is concluded that the decision-maker's preferences are nontransitive. The use of the UniComBOS method for this problem is unjustified.

The formulas under consideration. First, it is possible to determine whether a set of formulas is inconsistent or not. And secondly, some formulae are feasible.

The necessary condition for the comparability of vector estimates introduced in Chapter 6.6.5 is used in the procedure for checking the revealed preferences of the decision-maker for consistency. Theorems have been proved according to which the features of decision-makers' preferences written in the form of a set of clauses that make it possible to obtain comparisons of arbitrary vector estimates as logical consequences of known comparisons of vector estimates. Any set of revealed preferences of the decision-maker, represented in the form of binary relations and the corresponding formulas of the first-order predicate logic, can be checked for inconsistency.

Real alternatives are checked for the dominance of one over the other after each answer of the decision-maker. One alternative dominates the other if the evaluation of the first alternative is preferable or equivalent to the assessment of the second, according to each criterion, and the evaluation of the first alternative is superior to the evaluation of the latter is at least one criterion. The alternatives are equal if their estimates are the same or similar for each criterion. If it turns out that all the non-dominated alternatives are equivalent, the identification of the decision-maker's preferences stops, and a set of the best alternatives is presented. If it is not possible to identify a subset of the best alternatives, the identification of the decision maker's preferences continues.

6.6.7. The order of alternatives' comparison

After ordering the grades of estimates on the scales of all criteria, further identification of the decision-maker's preferences occurs by comparing pairs of assessments, triples of estimates, etc. To determine the order of presentation of vector estimates for comparison of decision-makers, the KOMPAS method uses a forecasting model that allows predicting the answers of decision-makers when comparing vector estimates. The model for predicting the behavior of decision-makers presented in Chapter 6.7.

A particular optimization procedure is used to find the next pair of vector estimates. The result of the process for optimizing the number of calls to the decision-maker at the stage of identifying his preferences is pairs of vector estimates and the order of their comparisons by the decision-maker.

In the model for predicting the behavior of a decision-maker, when comparing vector estimates and alternatives, an auxiliary forecasting function is introduced, which assigns a real number to a vector estimate or a group of estimates. The prediction function is not used to compare real alternatives and does not, in any way, affect the result of applying the method. It serves only to reduce the number of calls to decision-makers when comparing vector estimates and to obtain additional information.

The prediction function is recalculated after each decision of the decision-maker. A lot of non-dominated real alternatives are considered when comparing groups of assessments that differ in two criteria. One alternative is selected with the maximum value of the prediction function. The second alternative belongs to the set of non-dominated alternatives, which is incomparable with the first, and the value of the forecasting function for it is the maximum among such alternatives.

For this pair of alternatives, a set of pairs of estimation groups are searched for, ordered in increasing order of the difference of the prediction function for these pairs. In each pair, the groups of estimates consist of two estimates from the scales fixed for the given couple of criteria. The set of pairs of estimates groups is composed in such a way that, with specific comparisons in each pair, the two alternatives found above turn out to be comparable under the simplified model of decision-makers' preferences. A set of pairs of assessment groups is selected to identify preferences in which the difference of the prediction function for the first pair is maximum. These pairs are presented to the decision-maker, starting with the first. If any answer to the decision-maker does not coincide with the answer necessary for comparing real alternatives, the set of pairs is wholly recalculated.

The comparison of scores for two criteria is made under the condition of the same values for other criteria, as in the case of one criterion. These values are not shown in the comparisons due to the insignificance of the values of the rest of the criteria.

The entire set of previously performed comparisons is checked for consistency after each comparison of a pair of vector estimates, and a subset of non-dominated alternatives is selected under a simplified model of decision-maker preferences.

If it was not possible to solve the problem (to compare all non-dominated alternatives), based on comparisons by two criteria, the identification of the preferences of the decision-maker continues using comparisons of estimates by three criteria, then by four, etc. An increase in the number of criteria occurs until the proportion of decision-makers' answers leading to contradictions in the total number of answers exceeds a particular predetermined threshold value, or a subset of the best alternatives is found. A large number of contradictory answers of the decision-maker, exceeding the threshold value, indicates that comparisons of vector estimates for the current number of criteria are too difficult for the decision-maker. Therefore, a further increase in the number of criteria will make the information obtained unreliable.

The procedure used in the case of two criteria for the selection of pairs of assessment groups presented for the comparison of decision-makers is also applied in the case of three or more criteria.

After each comparison, the decision-maker's answers are checked for consistency just as the case of two criteria and the non-dominated alternatives are identified.

Taking into account the individual abilities of the decision-maker. For a person, the complexity of comparing a pair of vector estimates depends significantly on the number of differing estimates in the couple. If vector estimates differ in only two components, then their comparison is not difficult for most people. If there are more different components, then the complexity of comparing them between different people is different.

For each decision-maker individually, the maximum difficulty of the questions is dynamically determined based on how well he or she copes with comparisons of vector estimates. For each number of criteria in the compared vector estimates, it is calculated how many questions of this dimension $N_{all}(n)$ were asked, and for how many questions $N_{err}(n)$ the decision-maker changed his mind. The number of *Nerr*(*n*) also includes cases when the decision-maker gave different answers when comparing different representations of a pair of three or more criterion vector estimates. A person's ability to compare multi-criteria vector estimates is assessed by the proportion of responses leading to contradictions relative to the number of all decision-maker responses. It is determined by the ratio $N_{err}(n)/N_{all}(n)$. If, when comparing vector estimates of a particular dimension, the decision-maker regularly gives different answers with different representations of the same vector estimates and/or his answers often lead to inconsistencies in his preferences, this indicates that it is difficult for the decision-maker to compare vector estimates of such a dimension. In this case, the poll is terminated. To compare alternatives and select a subset of non-dominated alternatives, the information obtained by comparing vector estimates of the lower dimension is used.

Thus, checking the consistency of comparisons allows you to adapt the dialogue with a specific decision-maker to his ability to work with multi-criteria alternatives.

6.6.8. A flowchart method

Figure 6.10 shows a block diagram of the procedure for structuring the problem of identifying a subset of the best alternatives and the process for determining the preferences of the decision-maker.

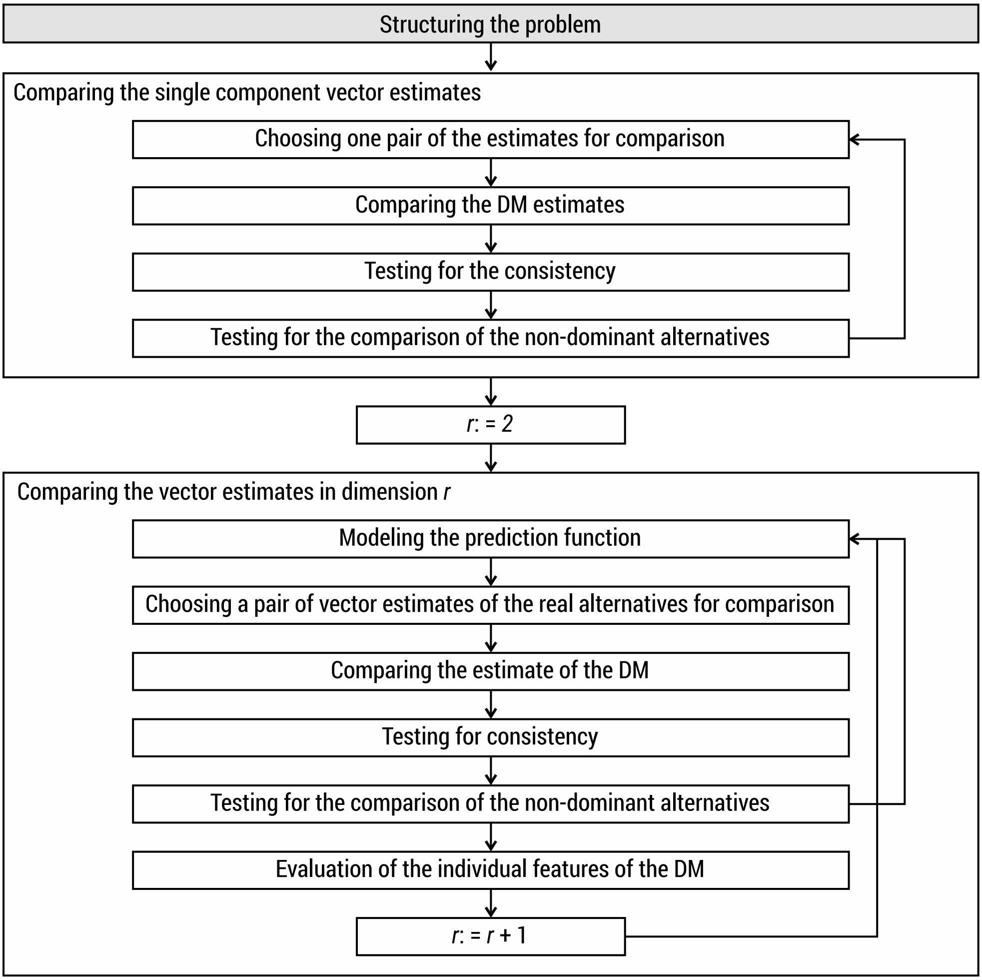


FIGURE 6.10. Flowchart of the procedure for identifying preferences of the decision-maker

6.7. UniComBOS decision making support system

The UniComBOS method is implemented in the DSS UniComBOS, designed to interactively help decision-makers in choosing the best alternatives based on their preferences. The system provides convenient user interfaces for:

- structuring the problem,
- dialogue with the decision-maker when identifying his preferences,
- displaying the results,
- analysis of contradictions,
- explanations for comparisons of vector estimates.

The system has a client-server architecture. The server runs on a computer with internet access. The client runs as a Java application on a computer that also has internet access, or on a computer running the server. Besides, the client can be embedded in the HTML document as an applet.

6.7.1. Structuring

At the stage of structuring, the decision-maker is proposed to formulate the choice problem in natural language, in terms of the corresponding applied area. The decision-maker must list the objects to be selected, and then determine the criteria for their estimates.

Criteria are the most significant aspects of objects for the decision-maker, so he must form a list of them. On the one hand, the more aspects of the problem are reflected in the list of criteria, the fewer chances that with the addition of unaccounted for parameters, the selection result will change. On the other hand, too many criteria can significantly complicate the task for the decision-maker. It should be kept in mind that the decision-maker is not always able to formulate all aspects that are significant for him when starting to address a new problem. In this regard, the UniComBOS system provides the decision-maker to return to the stage of structuring and supplement the set of criteria at any time. In this case, the already obtained information about the preferences of the decision-maker will, if possible, be used in the problem with an extended structure. Besides, at the stage of structuring, verbal assessments of all objects should be formulated for each criterion.

Figure 6.11 shows a UniComBOS screen with a table of ratings for the order of implementation of heritage projects by criteria.

TABLE 6.7. Table of ratings for the order of implementation of heritage projects by criteria

	Total project cost, thous. Eur	Project duration, months	Tourism, thous.	Architectural worth	Constructions, worth	Finishing, worth
Object 1	264.8	36	5.7	low	low	average
Object 2	552.2	60	48.9	average	low	low
Object 3	246.3	24	44.9	high	high	low
Object 4	473.7	60	8.1	low	average	high
Object 5	279.7	48	48.9	very high	very high	low
	min	min	max	max	max	max

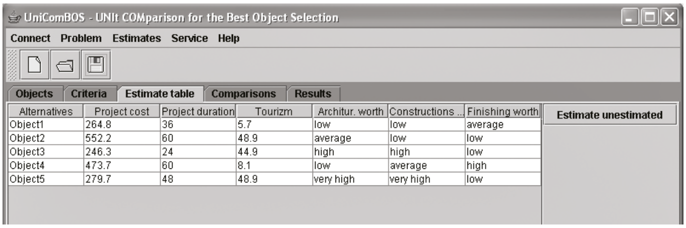


FIGURE 6.11. Structuring the problem

6.7.2. DM preferences identification procedure

At this stage, the system asks the decision-maker to compare vector estimates of different dimensions, starting with unit one (i.e., one-component vector estimates). The procedure for identifying the preferences of the decision-maker is organized following the block diagram in Figure 6.10. A comparison of one-component vector estimates leads to the formation of ordinal scales of assessments by criteria (Figure 6.12).

Then the system proceeds to the pairwise comparison of vector estimates of dimension two.

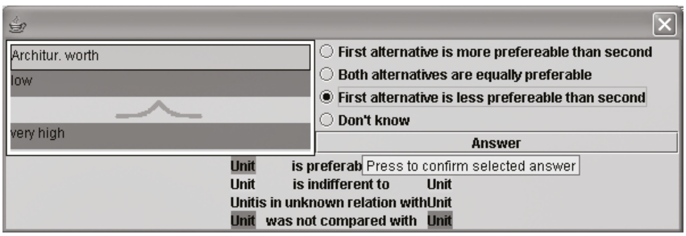


FIGURE 6.12 Comparison of scores by one criterion

Color differentiation. As noted above, the results of psychological studies show that a person reliably copes with the comparison of two-criteria vector assessments. Nevertheless, color differentiation is used to facilitate a comparison of two or more criterion vector assessments in the UniComBOS system. Concerning two-criterion vector estimates, this means the following. In each such pair of vector estimates $(a^{\{j_1,j_2\}}, b^{\{j_1,j_2\}})$, two pairs of one-criterion vector estimates $(a^{\{j_1\}}, b^{\{j_1\}})$ and $(a^{\{j_2\}}, b^{\{j_2\}})$, or which the decision-maker's preferences have already been identified. Therefore, when a pair of two-criterion vector estimates are presented to the decision-maker for comparison, the best estimates in each pair of one-criterion vector estimates are highlighted in one color, and the worst ones in another. Thus, the decision-maker immediately sees the advantages and disadvantages of each vector assessment according to the j^1 and j^2 criteria, which helps him when comparing them (Figure 6.13).

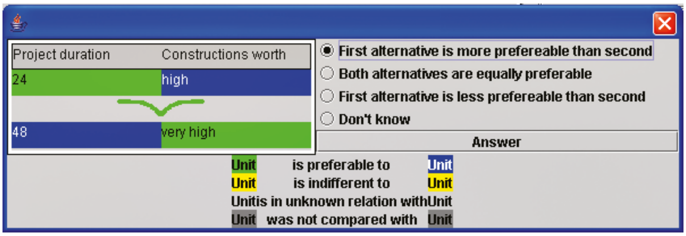


FIGURE 6.13. Comparison of two-criteria vector estimates

The totality of all his answers is checked for consistency after each answer of the decision-maker, and the vector estimates of the original alternatives are compared with each other to select a subset of non-dominated (maximum) alternatives. If a contradiction is found, the system offers decision-makers a procedure for its analysis and elimination. If in the set of non-dominated alternatives, all alternatives are comparable with each other, then this set is also the set of the best alternatives, and the problem is solved. Moreover, further comparison of vector estimates will not lead to a change in the set of non-dominated alternatives.

If it was not possible to select a subset of the best alternatives, after identifying the preferences of the decision-maker for all two-criteria vector estimates, the system proceeds to identify preferences for pairs of three-criteria vector estimates.

Since the comparison of three-criterion vector estimates is performed only after comparing all single-criterion and two-criteria vector estimates, the system "knows" which vector-dimensional estimates of one and two dimensions in each pair are considered the best and which are worse by the decision-maker. This is displayed on the screen in appropriate colors (Figure 6.14).

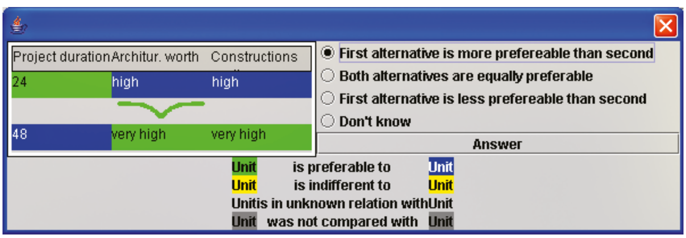
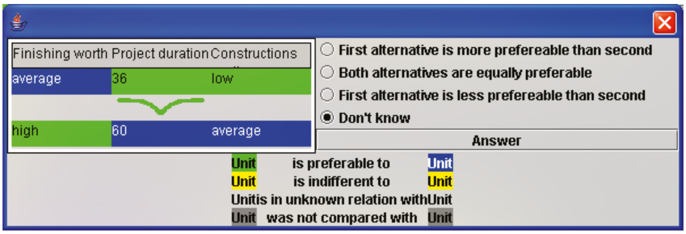


FIGURE 6.14. Comparison of three-criteria vector estimates

Let's note that each pair of three-criterion vector estimates can be split into two pairs of vector estimates of dimension one and two in three different ways (Figure 6.15). This provides additional opportunities for checking the consistency of the decision maker's answers since each pair of such vector estimates is shown three times in a different representation (using the corresponding color indication), and the three comparison results are checked for identity. While solving various problems using the UniComBOS DSS, it was noticed that the overwhelming majority of people did not see that the system offers them to compare the same pair of vector estimates in different representations. They compared these estimates again each time. Thus, the proposed approach has the following advantages over the usual comparison of vector estimate:

- additional check of the estimates for consistency,
- the ability to look at the problem of comparing a pair of vector estimates from several points of view,
- allows you to draw additional attention to complex comparisons.



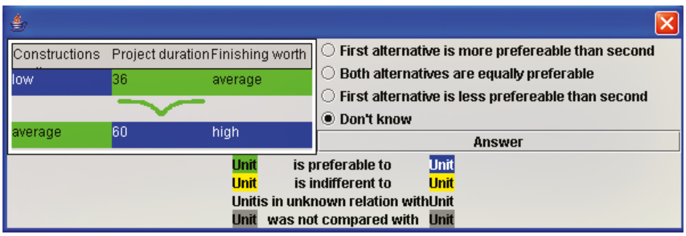


FIGURE 6.15. Comparison of the same vector estimates in a different representation

If mismatched answers are obtained, when comparing different representations of the same pair of vector estimates, they will be presented to the decision-maker for analysis and correction. Each four-criteria vector estimate can be represented in four different ways, five-criteria – in five, etc.

And again, after each answer of the decision-maker, his preferences are checked for consistency, and a subset of the maximum vector estimates is selected from the set of vector estimates of the original alternatives. If a subset of the best objects is selected, the problem is considered solved.

Comparisons of vector estimates differing in four or more criteria are carried out similarly. In the UniComBOS system, the maximum difficulty of the questions (the number of criteria in the compared vector estimates) is dynamically determined for each decision-maker individually, taking into account how well he copes with such issues. The frequency of his errors assesses the decision maker's ability to compare multi-criteria vector estimates. If the decision-maker regularly gives different answers with different representations of the same vector estimates in a pair and/or his answers often lead to inconsistencies in his preferences when comparing vector estimates of a particular dimension, this indicates that it is difficult for the decision-maker to compare vector estimates of such proportion. In this case, the polling stops, and the information obtained by comparing vector estimates of lower dimensions is used to compare alternatives. The system produces a subset of non-dominated alternatives.

The influence of color indication on a person's ability to compare vector scores is considered in (Furems *et al.*, 2003), showing that the complexity of comparing vector scores that differ in more than two criteria depends on the person solving the problem. It turned out that color indication helps to compare vector estimates of higher dimensiond.

6.7.3. Verification and elimination of contradictions

As mentioned earlier, the result of comparing a particular pair of vector estimates may lead to the decision maker's preferences being contradictory. In such cases, the UniComBOS system offers the decision-maker to analyze the contradiction that has arisen, determine its cause, and eliminate it (Figure 6.16).

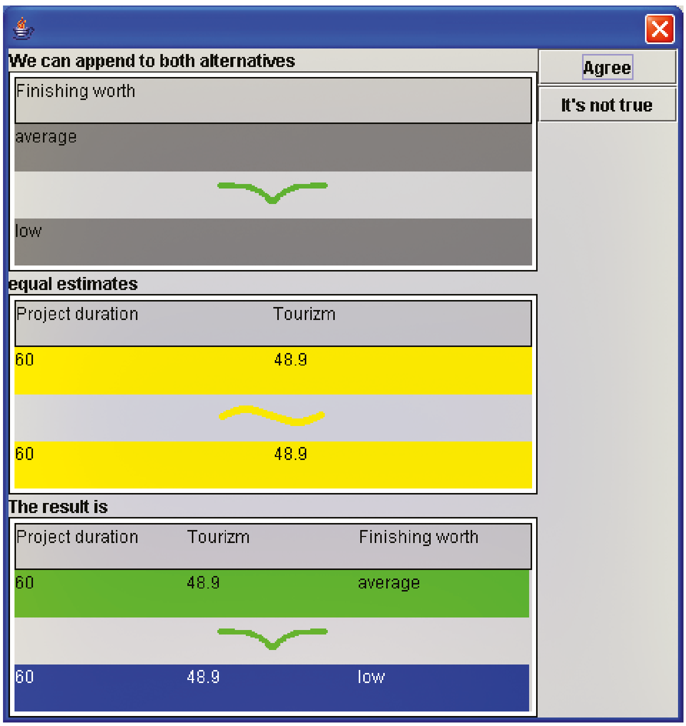


FIGURE 6.16. **Analysis of the contradiction**

This is done by presenting the decision-maker with his previous answers and the logical consequences from them. The decision-maker can point to a wrong answer or express disagreement with any intermediate result. In the first case, the decision-maker corrects his response. The second case means a violation of the hypothesis about the independence of preference and/or transitivity criteria and may require a restructuring of the problem.

Presentation and explanation of comparison results. The decision-maker can receive information about the ordering of the original alternatives at any time based on the comparisons he made. The comparison results are shown in the form of an oriented grandeur, in which the vertices correspond to the alternatives, and the arcs are directed from the object alternatives to the worst ones (Figure 6.17).

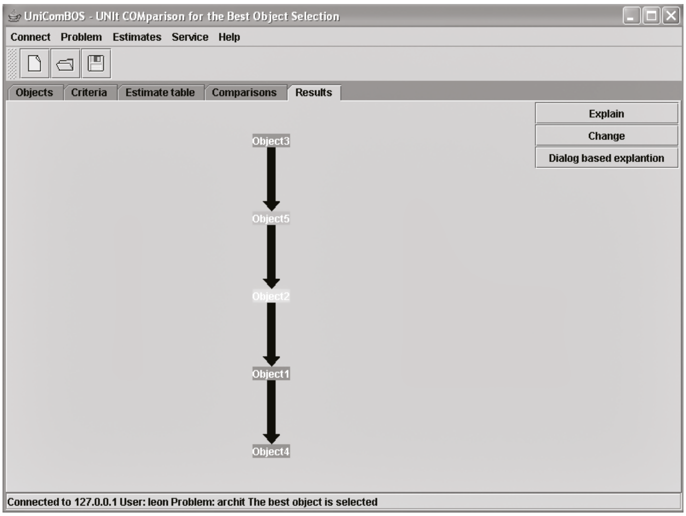


FIGURE 6.17. The results

The non-dominated alternatives are located at the top of the graph. If the decision--maker equally prefers some alternatives, the corresponding vertices are connected by a bi-directional arc. The decision-maker can call up an explain window for any arc of such a graph, and see how a similar relation is obtained from his answers. If the decision-maker does not agree with the conclusion, he can indicate in this window which of his previous solutions he wants to change. In this case, the system will return to the polling stage.

6.7.4. DSS software implementation

The solution of the multicriteria selection problem is carried out in the form of a dialogue with the decision-maker in the UniComBOS DSS, including the following stages:

- structuring the problem (enumeration of objects, criteria, evaluation of objectives by criteria);
- revealing the preferences of the decision-maker;
- preference consistency control;

- displaying relationships at objects;
- selection of the best object or group of the best;
- Explanation of results.

The main components of the UniComBOS DSS are shown in Figure 6.18.

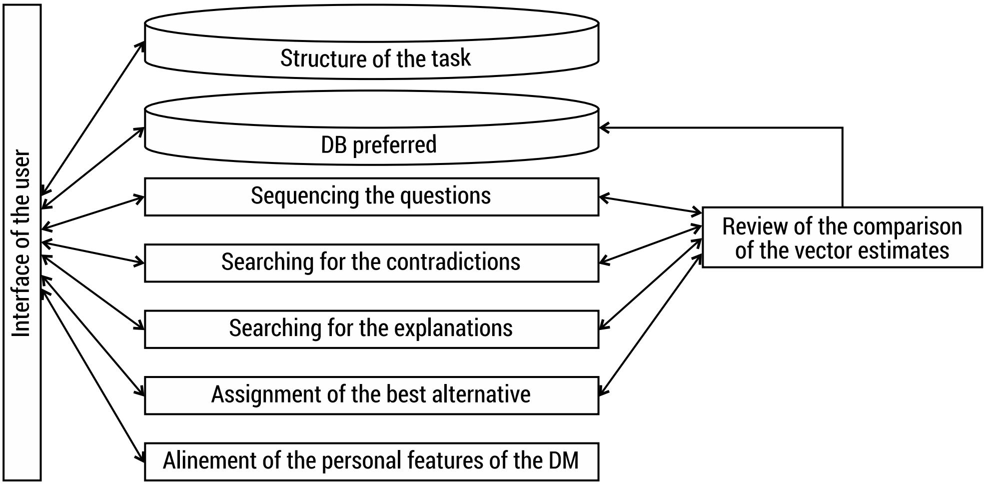


FIGURE 6.18. UniComBOS DSS components

DSS UniComBOS has a client-server architecture. The server handles JAVA applet connections and stores all data about users (DM) and the problems they solve. The client application is designed to work as a decision-maker with a task for an automated survey to identify the decision maker's preferences and analyze his preferences. The client and server are implemented in the JAVA programming language using the Forte™ for Java™4 CE development environment from SunMicrosystems.

Since the system is supposed to be used on the Internet, the JAVA programming language was chosen for implementation. Object orientation and the focus of the language on the development of applications for the World Wide Web are ideal for the task.

The UniComBOS application includes 66 java classes, aside from the classes of the standard JAVA libraries, classes for processing XML documents, and classes for solving linear programming problems. All data about the problem being solved is stored in the TProblem class. The decision maker's answers are stored in the lists of objects of the TAnswer class. Classes responsible for dialogue with decision-makers:
- JCompareDialog – the window for comparing two vector estimates,
- JExplainDialog – window explaining the comparison of two vector estimates based on the decision maker's answers,
- JSameAnswersContrDialog – a window was showing comparisons of two vector estimates in different representations if the decision-maker gave different answers when comparing them;
- JContradictionDialog – contradiction analysis window.

They all use JColorTablePane to display vector ratings and a preference icon in between (Figure 6.19).

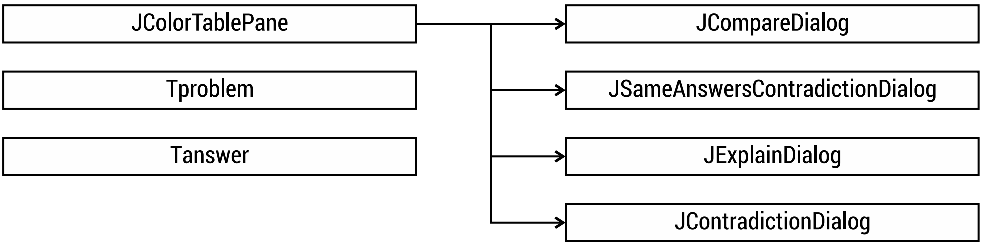


FIGURE 6.19. Classes of visualization of preferences of decision-makers

The computer decision support system UniComBOS was developed based on the KOMPAS method. It contains visual dialog components for information exchange with decision-makers, automated procedures for checking the comparability of arbitrary vector estimates, explanations, search, and elimination of contradictions in dialogue with decision-makers. Thanks to the use of computer programs, the dialogue with the decision-maker takes place in real-time, and the time spent on solving the problem is determined only by the complexity of the problem for a particular decision-maker.

The system provides color differentiation of estimates, reflecting the decision maker's preferences identified earlier to help decision-makers when comparing vector estimates.

The problem of choosing the best object from a given set is considered. The choice is made based on particular information about the preferences of a decision-maker. The proposed approach is based on the assumptions about the independence of preference criteria and preference transitivity, which, as a rule, are correct for a broad class of problems. Necessary and sufficient conditions for identifying inconsistency of preferences are determined. Inconsistency can arise as a result of an error in determining the preferences of the decision-maker, or because the specified assumptions are not fulfilled for a given task. It is important to note that the selection of a single object from a set is not guaranteed. The number of objects that fall into the best group is determined by information about the preferences of the decision-maker. It can be reduced with the help of additional information. Since the described approach is used in a computer decision support system, some other steps are proposed that give an idea of the algorithm for solving a problem using a computer.

7. Creation expert knowledge databases based on verbal classification

7.1. Two types of knowledge

Technologies that allow creating copies of human thinking in full have not yet been created. But successful steps are already being taken in this direction. Next, we will present the main ideas of a new computer system that allows to build exact copies of expert knowledge in classification problems.

The knowledge that one human generation passes on to another can be roughly divided into two types. One is the – facts, information, theories, problems, etc., included in books, textbooks in various disciplines and fields of science. Another type is the human ability to solve problems, compose music, treat patients, find faults in machines and apparatus, and so on. If knowledge of the first type (it is called declarative knowledge) can be obtained as a result of the primary learning process at school, at the university, then mastering knowledge of the second type (skill) is much more difficult. In life, skill is passed most often from teacher to student and is improved in the process of practical work by solving numerous problems. A person who is fluent in this or that skill is usually called an expert.

How does a person become an expert? What role do the experienced teachers, innate abilities, duration, and intensity of exercise play in this development? These questions have focused the attention of many researchers in recent years (Ericsson (b), 1996). Let us dwell briefly on some sufficiently confirmed characteristics of expert knowledge (skill).

Time and conditions for becoming an expert. First of all, the process of becoming an expert is long enough. It is a fact that it takes at least ten years to become an expert in any area of professional activity under favorable conditions (Ericsson (b), 1996). This fact is universal: it is right for such different fields as music and chess. World-renowned composers created the first high-level works not earlier than ten years of constant improvement. The best grandmasters, world champions, such as G. Kasparov, reached the heights of professional skill not sooner than ten years later. These examples can be multiplied (Ericsson (b), 1996).

Research has shown that regular exercise plays a significant role in becoming an expert. Two main factors – exercise time (in sports, music, chess, etc.) and the guidance of an experienced teacher, especially in the early stages of learning, is fundamental. As it turned out (Ericsson (a), 1996), a person's natural abilities are significantly less important. They can be actively developed through constant exercise, which is right for all people who do not have any congenital defects. Observations of musicians and athletes lead to the conclusion that the level of skill achieved is directly proportional to the time spent on exercise.

Transformation of the information processing system. It is believed that an expert acquires new qualities during his formation. In his brain, unique structures for storing specially organized information arise. Such arrangements are usually called knowledge bases.

The model of human memory is conditionally divided into short-term and long-term (see chapter 6.3). These two types of memory differ in volume and time of processing and storing the information. Problem analysis and decision making are usually carried out in short-term memory, which has a limited capacity. But this memory is fast enough, and the information in it is always at hand. Unlike short-term memory, the amount of long-term memory is substantial, but access to it takes much longer.

There is a reasonably proven hypothesis (Ericsson (a), 1996) that experts, as a result of many years of exercise, gain the ability to quickly access a specific part of their long-term memory, creating the so-called working memory that participates in problem-solving. Thus, an expert has the opportunity not only to "store up" a large amount of knowledge but also to have quick access to it.

Hierarchical structures for storing knowledge. The knowledge held by the expert is organized in a particular way, which makes it easier to find and use effectively. The information obtained over the years of study is not stored "just at random"; it is organized within specific structures.

First of all, solving similar problems over many years, an expert develops "his view", that is, the ability to describe problems with a set of features that allows for successful analysis. Thus, many chess players develop the ability to "see" in positions the possibility of an attack, an emerging danger, etc. They can quickly distinguish between typical configurations of the arrangement of figures. Doctors develop their skills to describe certain conditions of patients and recognize diseases.

As a rule, an economical (in composition) and practical (in use) set of features arises that describe the status of individual objects.

Further, objects are grouped according to such characteristics, which provides convenient storage of information and quick access to it. The universal structure is hierarchical: information is arranged according to some standard criteria, which, in turn, are also combined into groups, etc. A repository of knowledge appears, similar to an encyclopedia, provided with indexes for quick search (Kihlstrom, 1987).

A study of the processes of making diagnostic decisions by doctors (Lewicki *et al.*, 1992) showed that the knowledge of experts could be described quite accurately by a set of hierarchical rules based on the values of diagnostic signs.

The experiment for memorizing a large number of sequences of 6-10 digits by subjects (Richman, *et al.*, 1995) is quite impressive. After a year and a half, the subject remembered and accurately reproduced a large number of sequences. It turned out that he also used a hierarchical storage structure.

Characteristics of expert's behavior. So, the expert's memory is arranged in a particular way. How is this manifested in his behavior? The generally recognized characteristics of an expert's behavior are not only a quick solution to problems but also a rapid transition from considering a problem in solving it. A good doctor makes a diagnosis without delay. The grandmaster plays on several boards, and at a reasonable level.

It is generally accepted that experts are almost infallible in solving complex problems. This is proved by the games of outstanding grandmasters of the past, legends about the great doctors-diagnosticians. So, experts are unique individuals with invaluable knowledge and how to use it effectively.

The subconscious nature of expert knowledge. A natural question arises – is it possible to "ask" an expert how he solves specific problems? The answer to this question is negative – one of the essential characteristics of expert knowledge is its subconscious nature. Expert knowledge is not verbalized. This means that confidently solving his professional tasks, and an expert cannot explain precisely how he does it. Thus, the grandmaster cannot explain how he chooses the next move (except for simple positions), the composer – how he comes up with a melody, the doctor – how he makes a diagnosis (except for simple cases).

It is believed that the skills of people are unable to assess verbalization or explanation (Kihlstrom, 1987). Experts do not have informed access to their decision-making rules. All attempts to ask experts how they do it yield nothing, since people, at best, can only verbalize the simplest elements of their rules. In some cases (Lewicki, Hill, 1992), even direct prompts and the promise of additional rewards do not allow an expert to get a plausible explanation of the rules that guide him when making decisions. It is believed that skills are even stored in other parts of the human brain than declarative knowledge.

Difficulties in obtaining expert knowledge. The task of transferring expert knowledge to the computer has become one of the central problems of artificial intelligence for the last 20 years. Why transfer social skills and experience to a computer? First of all, so that the experience and knowledge of a qualified specialist are used not only by those people with whom he or she encounters but by a much more extensive range of possible users. The second, no less important goal, is not to lose the skills and knowledge of experienced people with the change of generations, to leave them available to humanity.

The task of constructing an artificial system with social skills to solve complex problems in some regions of activity is very attractive. But significant difficulties stand in the way of its solution. Let's list the main ones:

1. A person cannot communicate general abstract rules by which he is guided in solving a particular problem. His skills are most often stored on a subconscious level.

2. In any field of activity, there is a large number (tens and hundreds of thousands) of possible practical situations in the analysis of which a person's skills are manifested. These skills should be thoroughly mastered by a computer, which may require a lot of work and time of experts.
3. People who transfer their knowledge and skills to a computer in one form or another are inevitably mistaken. Whatever the cause of a specific error – fatigue, inattention, the difficulty of the situation – unfortunately, there are no infallible experts.

Let's note that there are different types of social skills, and a set of different approaches is needed to build their computer analogs. Next, we will present a method that allows you to create complete, consistent, and sufficiently large databases of expert knowledge (skills) for a particular class of problems: classification problems with specific features.

The problems of classifying objects described by many features are widespread in practice. Here are three examples:

1. Diagnosis of a disease, based on a combination of clinical and instrumental signs that describe the patient's condition, is the most common professional task in the daily activities of a doctor.
2. One of the most common tasks in geology is the search for a mineral deposit. The collection of information allows us to characterize various areas by a set of features that are more or less typical for deposits. On these grounds, the most promising areas are determined.
3. One of the everyday tasks in engineering is finding the causes of malfunctions, breakdowns in a complex machine or mechanism. A set of features can describe each analysis. It is on these grounds that the engineer determines the type of malfunction.

What is common in the activities of an engineer, geologist, doctor? This can be described as follows. There are objects with many characteristics. It is necessary to assign these objects to certain classes of solutions.

The essential characteristic of such decision-making problems is their frequency: people solve these problems many times, developing the most successful, practical solution skills. The number of repeated decisions is different for different areas of professional activity. The doctor daily solves the problem of recognizing the same object – signs of diseases in their various combinations. The issues associated with the choice of an area for development are resolved many times by the geologist. Unlike doctor and geologist, an engineer deals with changing objects (new designs of machines, mechanisms).

Complete set of features for a specific professional problem, their values, and classes of solutions is common in the above examples. The signs, the importance of which characterize the object and allow it to be attributed to a particular level, are set so that their measurements can, as a rule, be carried out either by another person or by a device.

So, the measurement of the percentage of a particular mineral in the soil is determined at the request of an expert geologist. Still, he does not necessarily participate in these measurements. The expert doctor determines the composition of the signs necessary for the diagnosis of a particular disease. Still, he uses the data of an electrocardiogram or ECHO-cardiogram, taken by his assistant. He can also advise over the phone or on the internet using the patient description given by another doctor.

The situation is quite different from chess players. The primary material is the arrangement of the figures. Analyzing the position of the pieces, the chess player characterizes it for himself by evaluations according to several signs, such as the possibility of developing an attack, a threat to the king, etc. The very measurement of the values of features is also part of the art (skill) of the expert.

Let us call the tasks of classification with explicitly specified attributes the tasks in which the skill of an expert is manifested mainly in the ability to "see" through a given set of values of individual attributes the integral image of an object. Classification problems with specific features are widespread in human practice. Further, we will only talk about such tasks.

7.3. A formal statement of the task of classification

The classification problem with specific diagnostic features can be formulated as follows (Larichev, Mechitov *et al.*, 1989):

Given:

Q – is the number of diagnostic signs;

w_q – is the number of ordered and, as a rule, verbal quality assessments on the scale of the q^{th} diagnostic attribute;

$S^q = \left\{k_1^q, \ldots, k_{w_q}^q\right\}$ – the set of estimates on the scale of the q^{th} feature

N – is the number of diagnostic classes to which the classified objects may belong.

Cartesian product of: $Y = S_1 \times S_2 \times S_3 \times \ldots \times S_Q$ determines the set of all hypothetically possible status described by diagnostic signs. The status y_i belonging to Y is defined by the vector $\left(y_{i1}, y_{i2}, \ldots, y_{iQ}\right)$, where the j^{th} component is one of the values on the scale of the j^{th} diagnostic sign.

Required:

To classify all vectors y_i based on the expert's knowledge, assigning each of them to one or more classes of solutions.

The peculiarity of this formulation of the problem is as follows. Suppose that an expert (doctor, geologist, engineer) has determined a complete set of diagnostic features that he needs in solving the classification problem. Then we are given the full space of all possible status of the research object (patient, field, mechanism, etc.). In the above formulation of the problem, the goal is to build a complete classification for the first time, that is, to classify all possible status of the research object. In contrast, it is usually about identifying some parts of knowledge in other formulations of the problem of identifying expert knowledge (Larichev, Morgoev, 1991; Shevchenko *et al.*, 2019).

This problem statement is based on the assumption the expert has complete knowledge. An approach is needed to identify them.

The main ideas of the expert classification method. Methods were developed based on the following purposes to solve the above problem (Larichev, Mechitov, 1989):

Structuring the problem. A common language is needed to transfer knowledge to a computer, to characterize a specific subject area (Larichev, Morgoev, 1991; Ševčenko, Ustinovičius, 2012). The language of features (or characteristics) describing the object of research is convenient. Such an object in the construction of medical knowledge base is a person who goes to a doctor with complaints of pain. Signs or characteristics, in this case, describe the patient's condition: localization of pain, their nature, irradiation, pulse rate, blood pressure, temperature, etc. These signs are determined when talking with an expert who can name signs that are important for setting diagnosis when looking at several situations.

The output of this stage – is a set of features necessary for a complete classification of objects of a particular type, all possible values of these features, as well as a list of decision classes.

Classification of status of the research object. The above characteristic features of expert knowledge make it possible to consider an adequate way of obtaining information from an expert when he solves a task familiar to him. A task for classification problems with clear signs is to analyze the description of the research object, given as a set of values of diagnostic signs. Such an analysis is familiar to an expert. It can be expected to manifest his knowledge fully.

A description of the problem is entered into the computer. The computer presents to the expert one of the possible status of the object of study in the form of a situation (CS), by combining the meanings of diagnostic signs.

Besides, the expert is given a list of solution classes from which he chooses his answer.

Specificity hypothesis. The hypothesis about the different specificity of the values of the diagnostic feature with each of the classes is actively used when receiving information from experts. In other words, it is assumed that the expert can order all the importance of each diagnostic feature according to their specificity for each of the decision classes and that this ordering does not depend on the importance of other features.

Let's take the i^{th} diagnostic feature. Any two values on its scale and for $n > m$are in the following characteristic relation for class C_j:

$$\left(k_{ni}, k_{mi} \in P^0_{C_j}\right),$$

where $P^0_{C_j}$ is the ratio of dominance by specificity for the class C_j. In other words, we introduced a binary dominance relation for the values of one diagnostic feature (more typical for the class C_j).

By their specificity for PA, these values can be ordered as follows: 3-2-1. For MI, the ordering by specificity is different: 2-3-1.

It is possible to construct a relation of dominance for specificity for each class on the set of status (vectors a_i) using binary relations of specificity for individual characteristics:

$$\left(y_i, y_j\right) \in P^0_{C_j},$$

if for each of the diagnostic features the values of the corresponding component of the vector y_i are no less characteristic for the class $C_j$than the value of the component of the vector y_j, and for at least one component the condition of dominance by specificity given above is satisfied.

The use of the hypothesis of specificity can significantly reduce the number of needed questions for an expert to build a complete classification.

Let the expert classify some status y_k of the research object into the class C_j. This means that the developed image of the object (according to the description) is characteristic of this class. At the same time, individual characteristics do not necessarily have the most typical values for class C_j. It is logical to assume that other status, the description of which coincides with y_k, except for the values of those diagnostic signs that are replaced by more typical for the class C_j, also belong to the class C_j. In formal language, it can be argued that the use of the hypothesis of dominance by specificity formulated above makes it possible to build a cone of dominance by specificity on the set of status Y. One expert's answer allows you to classify a group of status immediately.

We call the used rule a hypothesis because there may be cases where the distribution by specificity is incorrect. Such situations arise with the dependence of diagnostic signs. Therefore, the application of the hypothesis of specificity should be accompanied by its verification (see below).

Verification of expert information and hypothesis about specificity. There are no infallible experts, as noted. Therefore, the expert's data should be verified. This verification is based on the use of specificity dominance conditions.

Formally, such verification can be presented as follows. Let the computer – expert status y_i at some stage of the dialogue be assigned to the class C_j: $y_i \in C_j$. After each answer of the expert, distribution by dominance was carried out. In general, the constructed dominance cones intersect by their specificity. This means that some conditions can be classified multiple times.

Suppose that the classification of some state y_v does not coincide. Then, for example:

$$\left(y_v, Y_j\right) \in P \quad \text{but} \quad y_v \in C_l \ .$$

That is, y_v is more characteristic of the C_i class than y_i, but it turned out to be classified (with a different expert's answer) to the C_l class. This fact can also be a manifestation of the dependence of diagnostic signs along with a possible expert's error.

The computer presents the expert on the screen with descriptions of two status, if a contradiction in the classification is revealed, and asks him to analyze again. If the expert discovers his mistake, he corrects it, and the survey continues. If the expert confirms both different classifications, then:

- a subset of dependent diagnostic features is identified with the help of experts;
- these characteristics are combined into one aggregated characteristic that is independent of the others.

Analytical assessments show that, on average, about 25% of experts' answers are checked, which makes it possible to consider the constructed knowledge base consistent and reliably reflecting expert knowledge.

Determination of the sequence of status for presentation to the expert during the classification process. As shown above, the classification of the status of the research object allows one to classify indirectly (or reduce the uncertainty) of several other statuses. This makes it possible to construct a complete classification, that is, to solve the set problem by presenting a relatively small number of statuses to the expert. It is necessary to find a strategy for choosing the next status for presentation to an expert to implement this possibility.

The CLASS system (Larichev, Mechitov, 1989), as well as the following methods ORKLASS (Larichev, Moshkovich, 1996), DICKLASS (Larichev, Bolotov, 1996), KLARA (Larichev, Kochin, 2002), and CYCLE (Larichev, Asanov, 2000), differ from each other in the strategy of presenting states to an expert.

So, in the CLASS system, the most "informative" status is selected. It is assumed that all possible expert answers for any unknown status of the object are equally probable. For each unclassified status, the numbers of indirectly classified statuses are calculated for all possible expert answers. The average amount is calculated next, which characterizes the information content of the presentation of a particular vector. The computer enumerates all currently unqualified statuses and selects the one for which the expected average number of indirectly classified status is maximum.

The KLARA and CYCLE methods are significantly more effective (in terms of the number of calls to an expert).

The complexity of building knowledge bases. Computer systems for constructing complete and consistent knowledge bases pose an expert question after question until all states (all vectors y_i from the set Y) are assigned to one (or several) classes.

It takes from one to two weeks to one to two months of work with an experienced expert (depending on the volume of the knowledge base) to create knowledge bases in the way described above.

Let us give specific data for the CLASS system (Larichev, Mechitov *et al*., 1989). To create a knowledge base on seven coma states (2304 patient conditions are classified), it took 12 hours of expert work, for 14 statuses starting with pain in the abdominal region (about 20 thousand states) – 60 hours. The development of the first knowledge base took about seven days, the second – about a month.

The DIFCLASS system makes it possible to classify, on average, up to 700 states of the research object per hour (Larichev, Bolotov, 1996).

Verifying the quality of knowledge bases. The main criterion for verifying the constructed knowledge bases is the degree of coincidence of the decisions contained in it and made independently by the expert who participated in the creation of this knowledge base. An expert could evaluate each situation for small-sized tasks (about 100 diagnostic rules). He built the same knowledge base using the developed man-machine system after a while (two to three weeks).

Experts who solved the problem with a small number of contradictions, that is, who had clear rules, showed almost complete coincidence of their diagnostic rules. For large knowledge bases, comparisons were made for individual situations; the coincidence was practically finished. Consequently, the created knowledge base serves as a good reflection of the expert's personality, his "double" in a specific subject area.

Boundary elements of the classification. The constructed classification can be characterized using boundary elements. Let us call a boundary element a status that, under the constructed classification: a) belongs to the set E-P; b) may be in another class when only one value of one diagnostic sign changes. Boundary elements are called so because they seem to be "on the border" between two classes of solutions (they have many of the values of the features that are characteristic to each of the classes).

Let's note that boundary elements cannot be checked using the dominance relation by specificity when building a classification, so they are presented to the expert again after creating the classification.

It turns out that boundary elements can be used to describe classification rules that are subconsciously used by experts.

7.4. Key rules of experts

Studies show (Larichev, Bolotov 1996, Asanov A.A., Kochin 2002; Peckienė *et al.*, 2012) that class boundary objects can be described quite accurately by a relatively small number of rules with a tree structure (Figure 7.1).

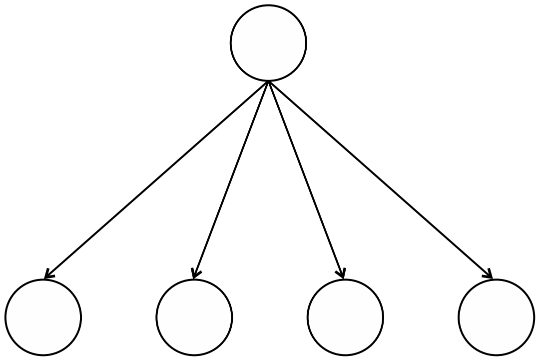


FIGURE 7.1. Decisive veto structure

In Figure 7.1 the top circle (the root of the tree) represents a set of values of diagnostic features that are most important for this class (for an expert). A certain number of values of less essential features characteristic of this class are added to them (bottom circles). For example, with five diagnostic signs, the rule for class C_1 may look like:

$$k_{21}k_{41} + C_3^2$$

or: the estimates of the second and fourth signs are characteristic of the first class (they must be present), to which you need to add any two value characteristics of C_1 from the remaining three signs.

It is important to note that both the complete set of boundary objects and the decisive veto describing them can be obtained only by building a complete and consistent knowledge base defining the expert's decisions for all possible objects. The partial knowledge base does not provide an idea of the actual decision rules used by the expert.

Experiments carried out using the DIFCLASS system in the problems of differential diagnostics allowed obtaining new data on the methods of decisive veto used by experts (Larichev 1995; Larichev, Bolotov, 1996).

The obtained results can be briefly characterized as follows:

1. Boundary elements can be described by a set of structurally simple diagnostic rules.
2. Each of the rules describes a part of the boundary elements that separate the classes of solutions.
3. An expert spends 2-3 times more on classifying a boundary element than on classifying the state of an object inside a class.
4. The number of decisive veto is limited by the volume of short-term memory and does not exceed eight.

5. Most often, the decisive veto is a tree built on the values of diagnostic features (Figure 1), where the most significant values for the class of decisions are at the root of this tree. A set of combinations of values of other characteristics is added to them (for example, no more than two characteristic values for this class of four characteristics).
6. The primary subconscious operations performed by experts are:
   - highlighting the most informative feature values (corresponding to the tree root) in the object description;
   - counting the number of characteristics characteristic of a given class and equally educational values of other characteristics.

The above results make it possible to understand how an expert classifies objects described by many features. The classification process consistent with known data, most likely, is as follows:
1. the expert "stores" in his long-term memory a set of decisive veto that allows describing the boundaries of decision classes, based on many years of practice. The number of these rules is small and does not exceed the volume of short-term memory;
2. the expert "transfers" the corresponding decisive veto into the short-term memory, upon presentation of the next object, compares the object with them and assigns it to the relevant class of decisions. If these rules do not allow the object to be classified, he replaces them with others from the complete set of rules developed in advance based on his long-term practice.

Formation of the implicit learning-based training systems. The revealed rules can become the basis for creating a training system based on the principle of implicit learning (Larichev *et al.*, 1989; Ševčenko, Ustinovičius, 2016). Such systems initiate the process of forming the expert's decisive veto in the head of a beginner, presenting him with a series of diagnostic tasks. The use of such systems makes it possible to master the practical diagnostic skills much faster.

It is customary to distinguish two types of knowledge: declarative and procedural. The second type of knowledge is usually called an ability, skills. Skills arise with constant exercises to solve specific repetitive tasks in various areas of human activity. A person who is fluent in the ability to solve repetitive tasks is usually called an expert.

It takes at least ten years to achieve high professional skills by an expert. During this time, in the memory of the expert, storage structures of information specially organized in a hierarchical form appear. Expert knowledge is mostly subconscious and cannot be verbalized.

The task of constructing computer copies of the expert's knowledge is one of the most difficult in the field of artificial intelligence. The main difficulties in extracting the expert's knowledge are their subconscious nature, a large amount of knowledge, and the inevitable mistakes of an expert.

The expert's classification approach is designed to build complete, consistent, and accurate expert knowledge bases in the problems of assigning objects to different classes of solutions. Key features of the expert classification approach:

a) structuring the problem;
b) presentation of object descriptions in the expert familiar form;
c) the extension of the expert's objects to other states (objects) using the relation of dominance by specificity;
d) checking the expert's information for consistency;
e) an effective strategy for interviewing an expert.

Class boundary elements can represent the constructed complete classification. Boundary elements can be described quite accurately using structured simple (two-level tree) decisive veto. The number of such decisive veto does not exceed the amount of short-term memory.

7.5. CLARA method for classification of the given set of alternatives

7.5.1. Introduction

There is a large class of decision-making problems when a set of alternatives is divided by a decision-maker into several categories ordered by quality. For example, when buying an apartment or a house, when exchanging an apartment, people usually divide alternatives into two groups: those that deserve more detailed information, that requires the expenditure of effort and resources to study, and those that do not. The physician examining patients can distinguish groups according to suspicions of different diseases. A commodity specialist can group products with quality. An applicant can differentiate between groups of universities according to their prestige. Likewise, people often identify book groups, clothing styles, hiking trails, etc.

The same challenge can arise when making decisions in an organization. For example, the bank's credit policy development should include a classification of bank customers into creditworthy and non-creditworthy.

Generally speaking, grouping objects together is a widespread activity for people. This is because classification is an entirely satisfactory solution for many practical problems, especially in the case when the number of objects is large enough. So, for example, it makes no sense to achieve a strict ranking of several hundred objects. At the same time, the division into several groups can give a completely satisfactory answer to the question of their quality. But the grouping also makes sense for a small number of objects, if the exact meaning of the problem determines it. Note also that the division of objects into groups is the result of the work of many expert systems.

One of such systems is the ORCLASS method (Larichev, Moshkovich, 1996). It is possible to divide the complete set of objects into classes ordered by quality, using this method, with each object being characterized by estimates according to several quality criteria. A complete set of objects means that the set contains objects with all possible combinations of criteria ratings, that is, all possible objects.

A set of objects can be classified simply by sequentially presenting them to all decision-makers. However, this will be a very irrational use of the decision maker's time. ORCLASS offers a survey procedure for the decision-maker, which allows to reduce the number of questions and thereby increase work productivity. However, in some situations, the classification of the complete set is not required, and only a small set of real objects needs to be split into classes. Such a problem can arise when there are a relatively small number of real objects, for example, dilapidated buildings which are subject to either demolition or reconstruction. Or if it is necessary to classify the full set of alternatives, which are very rarefied by alternatives with unacceptable combinations of evaluations by criteria (for example, in medicine, some symptoms are not combined, some are the result of other symptoms, etc.). In such cases, it makes no sense to classify the entire object space, but rather focus on specific real-world alternatives.

This problem is solved by the KLARA method (Larichev, Kochin, 2002) based on ORCLASS.

7.5.2. Formulation of the problem

Formally, the task can be represented as follows:
Given:

1. G – a feature that meets the target criterion of the task (value of the investment project, the severity of the disease, etc.);
2. $K = \{K_1, K_2, \ldots, K_Q\}$ – is a set of criteria by which each object is assessed (investment project, patient);
3. $S_q = \{k_1^q, \ldots, k_{w_q}^q\}$ for q = 1, ..., Q is the set of estimates by the criterion K_q, w_q is the number of gradations on the scale of the criterion K_q; the estimates in S_q are ordered in ascending order of specificity for property G;
4. $Y = S_1 \times, \ldots, \times S_Q$ is the space of states of objects to be classified. A set of criteria scores describes each object;
5. $C = \{C_1, \ldots, C_N\}$ is a set of classes of solutions, ordered in increasing order of the severity of property G;

6. $L = |Y| = \prod_{q=1}^{Q} w_q$ – redundancy Y;

7. $Y^a \subseteq Y$ – many real alternatives.

Since the estimates for each criterion are ordered, then each ordinal scale S_q of the q criterion can be associated with a quantitative scale $B^q = \left\{1, 2, \ldots, w_q\right\}$, where, if b_i^q is less preferable for the decision-maker than b_j^q.

This information about the preferences of the decision-maker determines the relation of strict preference (or dominance) P^0 on the set Y:

$$P^0 = \{(y_i, y_j) \in Y \times Y \mid \forall q \in K \ \ b_i^q \geq b_j^q \ \ \wedge \ \exists q^0 : b_i^{q^0} > b_j^{q^0}\}$$

On the other hand, it is known that the classes of solutions are ordered for decision-makers. This means that any alternative from class *n + 1* is preferable for decision-makers than any alternative from class *n*. The following binary preference relation can reflect this feature on the set Y:

$$P^1 = \{(y_i, y_j) \in Y \times Y \mid y_i \in Y_k, \quad y_i \in Y_l, \quad k > l\}$$

It is natural to assume that no vector estimate of the set Y that dominates the given one should be assigned to a less preferred class. This statement is known as the characteristic hypothesis. Formally, this can be written as follows:

$$(y_i, y_j) \in P^0 \Rightarrow (y_j, y_i) \notin P^1 \tag{7.1}$$

Definition. A partition of the set of vector estimates Y into ordered classes N is called consistent if condition (1) is satisfied for any $y_i, y_j \in Y$.

It is required: to construct a consistent mapping $F : Y^a \mapsto \{Y_l\}, \ l = 1, 2, \cdots, N$, on the basis of the preferences (judgments) of the decision-maker, such that $Y^a = \bigcup_{l=1}^{N} Y_l; \ Y_l \bigcap Y_k = 0$, at $k \neq l$, where Y_l is the set of vector estimates from Y, assigned to the class C_l.

7.5.3. Approach to the rational construction of a complete ordinal classification

In general, the solution to the problem of constructing a classification can be carried out by sequentially presenting the decision-maker of all vector estimates of the set Y^a for their classification. However, this approach is ineffective even for solving problems of relatively small dimensions (up to hundreds of vector estimates in Y^a).

The use of the hypothesis of specificity (1) can significantly reduce the number of required questions to an expert to build a classification. Let's identify the set of numbers of classes $Y_l(l=\overline{1,N})$ by G^i admissible for vector estimation $y_i \in Y$. Before the start of the decision-maker survey $\forall y_i \in Y \ G^i = \{1,2,\ldots,N\}$, since we do not have relevant information about the preferences of the decision-maker. Ultimately, all G^i is required to consist of only one element.

Let the decision-maker indicated that the vector estimate $y_i \in Y$ in terms of its total quality should belong to the class $Y_l(1 \le l \le N)$. Following the hypothesis of specificity, in this case, the vector estimate described by a set of criteria values that are no less preferable for the decision-maker, cannot belong to a less preferred class.

Likewise, a vector estimate described by a set of criterion values no more preferred than $y\, y_i$ cannot be of a more preferred class.

Therefore, the information obtained from the decision-maker regarding only one vector estimate from Y can lead to a decrease in the sets $G,^i$ corresponding to other vector estimates. Thus, in a particular case, it is possible to uniquely determine whether it belongs to a specific class of vector estimates that were not presented by the decision-maker.

The number of questions to the decision-maker can be reduced by using the ratio P^0 and the ratio P^I given on the set Y. The number of indirectly classified vector estimates depends on which point of the multidimensional space (formed by the Cartesian product of the criteria scales) is presented to the decision-maker, and into which the considered vector estimate will be assigned depending on the class. To assess the possible amount of information received from the decision-maker when presented to him with a particular vector from Y, one can calculate the number of indirectly classified states for each possible decision of the decision-maker.

The probability of assigning a specific vector to a particular class can also be taken into account. The indicator p_{il} (evaluating the probability of assigning the vector y_i to the class Y_l) is associated with the proximity of the vector under consideration to the representatives of this class, since vectors belonging to the same class, as a rule, form compact groups in a multidimensional space.

It is possible to construct a single quantitative assessment of the "information content" of each not yet assessed state Φ using these two indicators:

$$\Phi_i = f(\{p_{il}, g_{il} \mid l \in G^i\}) \tag{7.2}$$

where:

f – is some real function,

g_{il} – is the number of vectors from Y whose membership in a particular class becomes known (i.e., the cardinality of the corresponding set of class numbers G_i equals 1), if the decision-maker assigns the vector y_i to the class Y_l.

These ideas are the basis for a multi-step procedure for interviewing decision-makers, that can be presented in the form of the following enlarged stages:

1. A subset of alternatives Y_g is determined for which the set of relevant classes G^i contains more than one element. If Y_g turns out to be empty, then go to step 7.
2. For all alternatives from Y_g, we calculate the indicators p_{il} and g_{il} for $\forall l \in G^i$.
3. Based on these indicators, we calculate the information content Φ_i.
4. $y_i \in Y_g \ : \Phi_i = \max_{y_j \in Y_g} \Phi_j$ is determined.
5. This vector is presented to the decision-maker for assignment to one of the classes.
6. The sets G^i are modified following the class that the decision-maker indicated. Go to stage 1.
7. The end of the procedure.

7.5.4. Indicators of the informativeness in CLARA method

In the ORCLASS method (Larichev, Moshkovich 1996) the mathematical expectation of the number of classified vectors is used to construct a complete classification as a function of information content (7.2):

$$\Phi_i = \sum_{i \in G^i} p_{il} g_{il} \tag{7.3}$$

To classify a given subset, we need to maximize the number of real alternatives, the classes of which become known with a given choice of the decision-maker. That is, we must count only those alternatives that belong to Y^a when calculating indicators g_{il}. Thus, it is necessary to change the calculation of information content to achieve our goal. As before in formula (7.3):

$$\Phi_i = \sum_{i \in G^i} p_{il} g_{il}^a \tag{7.4}$$

only here g_{il}^a – is the number of vectors already from Y^a (and not from Y, as in (7.3)), the belonging of which to a particular class becomes known, if the decision-maker assigns the vector y_i to the class Y_l.

However, the pure mathematical expectation of the number of indirectly classified vectors does not reflect the information content well enough. The actual number of indirectly classified vectors will fluctuate around this value, which might be quite large. For example, the alternative with the highest estimates in all criteria except one (with the one point lower estimate in a task with two classes) may have the most significant information content because it will determine the dominance of the alternative when being assigned to the lower class. Although, the probability that the decision-maker will classify it precisely as a lower class, calculated from the distances to the centers of the classes, will be less than the probability of the opposite event. It can still be high enough to provide the maximum mathematical expectation – informational content. As a result, this alternative will be presented, and the decision-maker will surely classify it as a higher class, which will give absolutely no information about the other alternatives.

In connection with the above, there is a desire to take into account the possible spread in the number of indirectly classified alternatives. Consider the coefficients from the formula for information content as a random variable with the probabilities of realizing the *lth* value p_{il}. Then, $\Phi_i = M\Gamma_i$ – where $M\Gamma_i$ is the mathematical expectation of a random variable Γ_i. The value that well characterizes the spread of a random variable Γ_i relative to its average $M\Gamma_i$ is the standard deviation $\sigma_i = \sqrt{D\Gamma_i} = \sqrt{M(\Gamma_i - M\Gamma_i)^2} = \sqrt{M\Gamma_i^2 - (M\Gamma_i)^2}$, where $D\Gamma_i$ is the variance Γ_i (Chistyakov 1996). However, it is not the absolute deviation that is important to us, but the relative one. Indeed, more significant differences can be allowed for larger values. Therefore, characterizing the information content as a value, it is worth taking the function:

$$\tilde{\Phi}_i = \frac{\Phi_i}{1 + n\dfrac{\sigma}{\Phi_i}} = \frac{\Phi_i}{1 + n\dfrac{\sqrt{\sum_{l\in G_i} p_{il}(g_{il}^a)^2 - \Phi_i^2}}{\Phi_i}}, \quad n \geq 0 \tag{7.5}$$

Indicating:

Φ_i – is the informative in the old sense, and is the mathematical expectation of g_{il}^a,
σ/Φ_i – this ratio is the relative deviation of indicators g_{il}^a from their average value,
1 – is added to the denominator for the last one to be not least than one (and therefore greater than zero),
n – is an empirical factor with a relative deviation, let's call it the level of variance significance. This factor allows to set a measure of the influence of the difference in the information content. When $n = 0$ turns out to $\tilde{\Phi}_i = \Phi_i$, that is –informational content without taking the variance into account.

Such a task of informativeness makes it possible to exclude "risky" situations when the decision-maker is offered an alternative with significantly different numbers of indirectly classified alternatives (depending on the decision maker's answer) for assessment. The bigger *n*, the smaller the spread is allowed. However, for a very big *n*, there is a danger that an alternative may not be presented to the decision-maker, even if it has a substantial mathematical expectation. The selection of the optimal level of variance depends on each specific task and requires caution.

7.5.5. DSS CLARA

A computer decision support system that implements the CLARA method was developed based on these ideas. The program works in the Windows operating environment and has a friendly interface inherent in this environment.

The initial information is:

1. a system of criteria describing any possible object of classification. Scales of criteria – ordinal with verbal formulations of quality for each criterion. The number of criteria – up to 15, the number of gradations on the levels of criteria – up to 10;
2. the number of classes into which the partition is made. This system supports up to 10 classes;
3. a real set of alternatives that need to be divided into classes. There is a possibility in the program not to specify this set, and then a complete classification will be carried out;
4. level of significance of variance. This coefficient is set as an external parameter and can be changed by the user not only at the beginning but also during the program operation.

Since there is a finite number of criteria (Q) and each criterion has a scale with a limited number of discrete estimates, it is possible to form the set of all potential vector estimates in the criterion space (Cartesian product of all estimates on the criteria scales) with the number of elements L. The system allows constructing a classification as all elements of the Cartesian product, and its specified subset based on the presentation of the decision-maker a part of these objects for classification.

Formatting a consistent classification of selected objects. After determining the structure of the problem (criteria and rating scales for these criteria), as well as a subset of real alternatives Y^a, the CLARA system forms a set of hypothetical objects Y and for each of them determines a set of admissible classes $G^i\left(i=1,2,\ldots,L\right)$. These sets equally contain all classes (from 1 to N) for all elements of the set Y at the initial stage. Except for y_1, which corresponds to the element with all the least preferred estimates according to the criteria, and y_L, corresponding to the element with all the most preferred estimates according to all criteria.

Following this information, the CLARA system calculates the information content of each of the elements of the set Y according to formula (5). After that, the element y_i, with the maximum value of information content is selected and presented to the decision-maker for classification.

If the decision maker's answer (the class for the presented alternative) is within the permissible classes (condition (1) is satisfied), then it is considered final and is entered into the set G^i. Further, following these data, the sets G^j for y_j, which are dominated or dominated by y_i, are recalculated.

After that, the presence of elements of the set Y^a is checked, the belonging of which to one of the permissible classes is not determined. If there are no such elements, then the classification of the selected set is wholly constructed. If there are such elements, then the informative indicator is recalculated for them. The most (potentially) informative element is selected and presented for the decision-makers classification.

If the decision maker's answer goes beyond the classes allowed for a given element (that is, condition (1) is violated), then the system issues a corresponding message and offers the decision-maker to change his last answer or analyze the situation that has arisen. If the decision-maker insists on his previous answer, the program switches to the contradiction elimination mode and presents a pair of conflicting alternatives to reassign their classes. This process continues until all contradictions disappear.

7.5.6. Statistical modeling

It is interesting to evaluate the effectiveness of the method, that is, how much the actual number of questions asked by the decision-maker differs from the minimum possible. Let the classification have already been carried out. What is the minimum number of questions a decision-maker could ask to get it? The minimum number of questions will be obtained if only all boundary alternatives are presented to the decision-maker. Indeed, boundary elements are, by definition, all non-dominated (upper bound) and non-dominated (lower bound) class members. Thus, knowing the upper and lower bounds of a class, spread overdominance can obtain all other alternatives of this class. And vice versa. No element of the boundary can be obtained by spreading by dominance (indirectly classified), since for each indirectly classified element, there are two elements of the same class that are different from it, one of which dominates it, and the second is dominated by it. And all boundary elements are undominated or non-dominant.

Thus, the minimum number of questions that a decision-maker needs to ask to obtain a given classification is the number of elements within the boundaries of the classes. Of course, it is necessary to subtract the best and worst alternatives from the number of these elements, which, by definition, belong to the best and worst class, respectively, and decision-makers are not presented.

The minimum number of questions for decision-makers is fundamentally unattainable since this requires knowledge of class boundaries already before classification. However, it makes sense to compare the actual number of questions asked with the minimum possible. We will look at the relationship $\frac{\textit{real number of questions}}{\textit{minimum number of questions}}100\%$ and call it *efficiency*. he definition shows that the closer the efficiency is to 100%, the closer the real number of questions is to the minimum. Performance can depend on the number of criteria, the number of classes in the problem, and the size of the subset to be classified. Let's try to find out this dependence using statistical modeling.

Statistical modeling to assess the effectiveness of the ORCLASS method on a set of real alternatives, taking into account variance, was constructed as follows. The number of criteria and the number of classes are set. The number of ratings on the criteria scales is fixed and equal to 3. A classification rule is generated. The level of variance is set. Then, randomly from the full set of alternatives for this problem, half, third, quarter, and fifth of all elements are left, and each time a classification is carried out. The program records the average number of questions to the decision-maker, the average minimum number of questions (the number of boundary elements), and the optimal level of variance, that is, the level of variation at which the least amount of questions was asked. The results are summarized in Table 7.1.

TABLE 7.1. Statistical data for evaluating the effectiveness of the ORCLASS method

Criteria	Part of the multitude	Capacity	Classes								
			2			3			4		
			Variance	Question	Efficiency	Variance	Question	Efficiency	Variance	Question	Efficiency
2	1/2	4	0.00	2.21	77.90	0,00	2.96	98.31	0,00	2.93	99.57
	1/3	3	0.00	1.83	82.25	0,00	2.14	99.42	0,00	2.24	99.72
	1/4	2	0.00	1.33	90.09	0.00	1.41	100.00	0.00	1.49	100.00
	1/5	1	0.00	0.72	100.00	0.00	0.73	100.00	0.00	0.71	100.00
3	1/2	13	1.50	5.58	49.10	1.50	10.03	75.52	1.50	10.20	84.32
	1/3	9	1.50	4.62	59.15	1.50	7.31	85.41	1.50	7.45	90.65
	1/4	6	1.50	3.68	67.91	1.50	5.07	92.85	1.50	5.12	95.52
	1/5	5	1.50	3.25	71.03	1.50	4.28	95.52	1.50	4.27	96.59
4	1/2	40	2.00	14.09	46.22	2.00	24.07	63.11	2.00	26.76	71.22
	1/3	27	2.33	12.34	50.71	2.50	19.30	71.37	2.33	20.48	79.54
	1/4	20	2.50	10.20	58.64	2.50	15.57	78.59	2.50	16.13	83.60
	1/5	16	2.67	8.90	63.97	2.63	13.03	83.50	2.50	13.33	86.25
5	1/2	121	2.75	27.04	32.50	2.45	54.66	39.85	2.25	66.17	48.23
	1/3	81	2.75	23.87	35.85	2.63	45.32	47.15	2.33	52.65	60.04
	1/4	60	3.00	21.61	38.21	2.63	38.71	52.68	2.33	43.24	68.40
	1/5	48	3.25	19.63	41.13	2.80	33.51	58.43	2,50	36.88	73.45
6	1/2	364	3.38	70.32	27.48	2.75	113.17	34.05	2.25	156.73	36.91
	1/3	243	3.38	63.27	30.34	2.63	100.54	37.51	2.38	133.99	45.35
	1/4	182	3.45	55.75	34.04	3.25	90.35	40.99	3.13	112.66	52.06
	1/5	145	3.63	51.33	36.52	3.50	80.90	44.73	3.00	95.90	58.25

The table for a given number of classes and criteria, as well as for a given real part of the complete set, shows the optimal level of variance, the average number of questions to the decision-maker. As well as efficiency, that is the number of percentages that make up the unattainable minimum number of questions from the real one. For example, for a task of 5 criteria and 3 classes, for the classification of ¼ of all alternatives, the optimal level of variance turned out to be 2.63, the decision-maker was asked 38.71 questions, and the efficiency was 52.68%.

The optimal values of the level of variance grow with an increase in the dimension of the problem (the number of criteria) and decrease with an increase in the number of classes and a decrease in the part of real alternatives, as can be seen from the above table 7.2. Immediately, you can make some recommendations for choosing the level of variance for a particular class of problems, which are summarized in the following table:

TABLE 7.2. Optimal values of the level of dispersion

Criteria	Class		
	2	3	4
2	0	0	0
3	1,5	1,5	1,5
4	2,4	2,3	2,2
5	3,0	2,7	2,4
6	3,5	3,1	2,6

It shows the value of the optimal level of variance for problems with different numbers of criteria and classes. For example, for a problem with 5 criteria and 3 classes, the optimal level of variance should be chosen equal to 2.7. This table does not guarantee that the number of questions at a given level of variance will indeed be minimal. It suggests merely such an interval of values that when choosing the level of variance from it, the number of questions asked by the decision-maker is likely to be less than if using a different value.

Let us now trace the dependence of efficiency on the dimension of the problem. As can be seen from the table above, the efficiency decreases with an increase in dimension and increases with an increase in the number of classes. Besides, it can be seen that the smaller the subset, the closer the number of questions is to the minimum limit. However, at high dimensions, the classification efficiency becomes very low. And the application of the ORCLASS method for large dimensions can be justified only with a small size of the classified subset.

The CLARA method, developed within the framework of the expert classification approach and belonging to the group of Verbal Decision Analysis methods, has the following important properties:

1. the method allows constructing both a complete classification and a classification of a given subset of alternatives;

2. submission of descriptions of objects to the expert occurs only in the form familiar to the expert, and no artificial intermediate numerical data are used;
3. the expert's information is checked for consistency;
4. An effective strategy of interviewing an expert is used (in terms of the number of questions asked).

7.6. Development of a multi-criteria verbal assessment method CLARA (Classification of Real Alternatives)

Many decision-making methods have been developed around the world for a variety of human activities. VGTU prof L. Ustinovichius in collaboration with ISA RAN academic D. Kochin, developed the CLARA method. The dissertation is a co-author of the development of this system. The multi-criteria verbal analysis method, which classifies real alternatives, allows to perform multi-objective analysis of variants from different perspectives.

The CLARA method (Classification of Real Alternatives) is designed to solve the classification problem. This method can perform the classification of both the whole set of objects and the known part of the set by minimizing the number of expert requests. The method can also be applied to a loosely linear sequence of criteria scales.

The priority and significance of the options considered by this method directly and proportionally depend on the system of indicators, indicators of values, and importance of indicators, that adequately describe the possibilities. The values of the indicators are determined, and experts calculate the significance of the values of the indicators. All this information can be adjusted by the stakeholders (customers, etc.) according to their intended goals and available capabilities. Therefore, the results of the assessment of the options reflect the initial data provided jointly by experts and stakeholders.

Basic definitions. Let's introduce some formal definitions:

Definition 1. The alternatives $\boldsymbol{x}, \boldsymbol{y} \in \boldsymbol{Y}$ are called *comparable*: $\boldsymbol{x} \sim \boldsymbol{y}$, if $\boldsymbol{x} \geq \boldsymbol{y}$ or $\boldsymbol{y} \geq \boldsymbol{x}$ otherwise they are called *incomparable*: $\boldsymbol{x} \nsim \boldsymbol{y}$.

Any two alternatives belonging to one class are either in a dominant relationship or are incomparable so that in each class, a subset of non-dominant and non-dominant alternatives can be distinguished.

Definition 2. A subset of alternatives $B^U(C_n)$ of class C_n is called the upper bound of this class if $\forall \boldsymbol{x}_{\in} C_n \exists \boldsymbol{y}_{\in} B^U\left(C_n\right)$ such that $\boldsymbol{y} \geq \boldsymbol{x}$ and $\forall \boldsymbol{x}, \boldsymbol{y}_{\in} B^U\left(C_n\right), \boldsymbol{x} \neq \boldsymbol{y} \Rightarrow \boldsymbol{x} \nsim \boldsymbol{y}$.

Definition 3. A subset of alternatives $B^L(C_n)$ of a class C_n is called the lower bound of this class if $\forall \boldsymbol{x}_{\in} C_n \exists \boldsymbol{y}_{\in} B^L\left(C_n\right)$ such that $x\, y$ and $\boldsymbol{x} \geq \boldsymbol{y}$ and $B^L\left(C_n\right)$, $\boldsymbol{x} \neq \boldsymbol{y} \Rightarrow \boldsymbol{x} \nsim \boldsymbol{y}$.

The task of order classification can be solved by presenting the expert with all the alternatives card (Y*) to obtain the desired breakdown into classes. However, the application of the dominance ratio (1) and the non-contradiction clause (2) makes it possible to significantly reduce the number of directly submitted alternatives and, at the same time, speed up the classification procedure. The possibility to reduce the number of proposed alternatives arises from the use of information on already classified alternatives to classifying the remaining alternatives.

We will need the numerical functions $C^U(\boldsymbol{x})$ and $C^L(\boldsymbol{x})$ defined for the set Y as the maximum and minimum class numbers allowed. Respective $\boldsymbol{x}$ – is a class to which $\boldsymbol{x}$ does not violate the condition of consistency of classification (2). Let us consider the vector $\boldsymbol{x}$ to be classified and belonging to class C_k if the condition $C^U(\boldsymbol{x}) = C^L(\boldsymbol{x}) = k$ is maintained. Initially, $\forall \boldsymbol{x}_{\in} Y^*$ must be $C^L(\boldsymbol{x}) = 1, C^U(\boldsymbol{x}) = M$.

There is a set of alternatives Y in which the dominance ratio P is known, as well as M decision classes arranged in order of quality. For each alternative $\boldsymbol{x} \in \boldsymbol{Y}^*$, the maximum and minimum numbers of the permitted solution classes $C^U(\boldsymbol{x})$ and $C^L(\boldsymbol{x})$ are related. Before starting the classification $\forall \boldsymbol{x}_{\in} Y : C^L(\boldsymbol{x}) = 1, C^U(\boldsymbol{x}) = M$. The classification is considered to be formatted when $\forall x_{\in} Y : C^L(\boldsymbol{x}) = C^U(\boldsymbol{x})$.

Definition 4. Alternative $\boldsymbol{x} \in \boldsymbol{Y}$ *directly dominates* the alternative $\boldsymbol{y} \in \boldsymbol{Y}$ when $\boldsymbol{x \phi y}$ and $\nexists \boldsymbol{z} \in \boldsymbol{Y}$: $\boldsymbol{x \phi z \phi y}$.

Definition 5. The alternative $\boldsymbol{x} \in \boldsymbol{Y}$ is *directly dominated* by the alternative $\boldsymbol{y} \in \boldsymbol{Y}$ when $\nexists \boldsymbol{z} \in \boldsymbol{Y}$: $\boldsymbol{x \pi z \pi y}$.

The set of alternatives that directly dominate alternative $\boldsymbol{x}$ is marked as $Z^U(\boldsymbol{x})$ and the set of dominant alternatives is marked as $Z^L(\boldsymbol{x})$.

Definition 6. The direct domination alternative orgraph $G(Y, E)$ is an oriented acyclic graph in which the set of vertices is the set of alternatives Y, and the set of arcs $E \subseteq Y \times Y$ consists of elements $(\boldsymbol{x}, \boldsymbol{y})$ in which alternative $\boldsymbol{x}_{\in}\boldsymbol{Y}$ directly dominates alternative $\boldsymbol{y}_{\in}\boldsymbol{Y}$.

Definition 7. The sequence of alternatives $\boldsymbol{w} = \boldsymbol{y}_1, \boldsymbol{y}_2, \ldots, \boldsymbol{y}_l$, where $\boldsymbol{y}_{i+1\in} Z^L(\boldsymbol{y}_i)$, $1 \le i \le (l-1)$, is called a *chain*. The number $\boldsymbol{w}$ of the alternative chain L ($\boldsymbol{w}$) = l is called the chain *length*. A separate alternative is a chain of length 1.

Algorithms of classification. The CLARA (Classification of Real Alternatives) algorithm is based on the idea of the dichotomy of alternative chains, starting with the maximum length of the chain, first used in the DIFLASS algorithm (Larichev, Bolotov 1996), then in the KLANŠ algorithm (Naryznyi 1998), and applied to a ripe range of *Y*. CLARA uses a new idea of adaptive dichotomy that enables the faster finding of classes and accelerates classification.

Let us examine the main steps of CLARA the classification algorithm:

1. At the beginning of the classification, the dichotomy coefficient d_i for the search for C_i and C_i + 1 classes is considered to be equal to ½.

2. The dominant orgraph of alternatives $G(Y, E)$ may have several binding components. Therefore, all possible but not yet classified set alternatives Y^* are investigated in sequence. Consistency in the selection of alternatives is essential and is determined in a certain way, which will be described below. The ordinary selected alternative x_s is called the initial one.

In this connection component of $G(Y, E)$ of the orgraf (to which x_s belongs), a chain of alternatives of maximum length $\boldsymbol{w}_{max}$ is formed, passing through the initial alternative x_s and having the maximum number of as yet unclassified alternatives from Y^*.

3. Since the classes $\{C_n\}$are arranged according to quality, the sections between the classes in the chain are formed consistently, distinguishing the higher quality class C_n from the lower quality class C_{n+1}.
4. The chain $\boldsymbol{w}_{max}$ element $\boldsymbol{x}_d$ is distinguished, to present to the expert, where $d = d_n L(\boldsymbol{w}_{max})$ is, and if the alternative $\boldsymbol{x}_d$ proves to be impossible or already classified, then a new $\boldsymbol{x}_d$ takes the unclassified possible chain element with the nearest index.
5. A possible alternative $\boldsymbol{x}_d$ of the $\boldsymbol{w}_{max}$ chain is presented to the expert, and its solution is valid for the maximum possible number of elements whose dependence on C_n and C_{n+1} classes are not determinate.
6. If $\boldsymbol{w}_{max}$ still has possible unclassified elements, then the dichotomy of the $\boldsymbol{w}_{max}$ chain continues, ending when all possible alternatives that appear to be directly or indirectly classified for classes C_n and C_{n+1}. Otherwise, another mode is searched between classes (return to step 4). And if the chain is classified for all classes, then for each class, there is an index k in the $\boldsymbol{w}_{max}$ chain, where there is a change from class C_n to class C_{n+1}. Must be $d_{nw} = k \,/\, L(w_{max})$. In each subsequent step, d_n is the arithmetic mean of all previously calculated d_{nw}.
7. The cycle is continued until all possible alternatives in the possible set Y^* are classified concerning the pair of these two classes.

The general scheme of the CLARA algorithm is presented in Figure 7.2.

Estimation of the computational complexity of the algorithm. The computer system implementing the CLARA algorithm must maintain a dialogue by continually asking questions to the expert until the full classification is completed. Therefore, it is essential to evaluate the computational complexity of the CLARA algorithm, since the time required to complete the steps in determining another alternative to be provided to the expert is the time during which the expert waits for a routine request from the system. The computational complexity of the KLANŠ algorithm was estimated (Naryznyi 1998), and itwas $O(|Y| log_2 |Y|)$. The computational complexity of the CLARA algorithm is determined analogously. Let the classification problem have two classes of solutions, and each criterion is described by only two estimates arranged according to its properties.

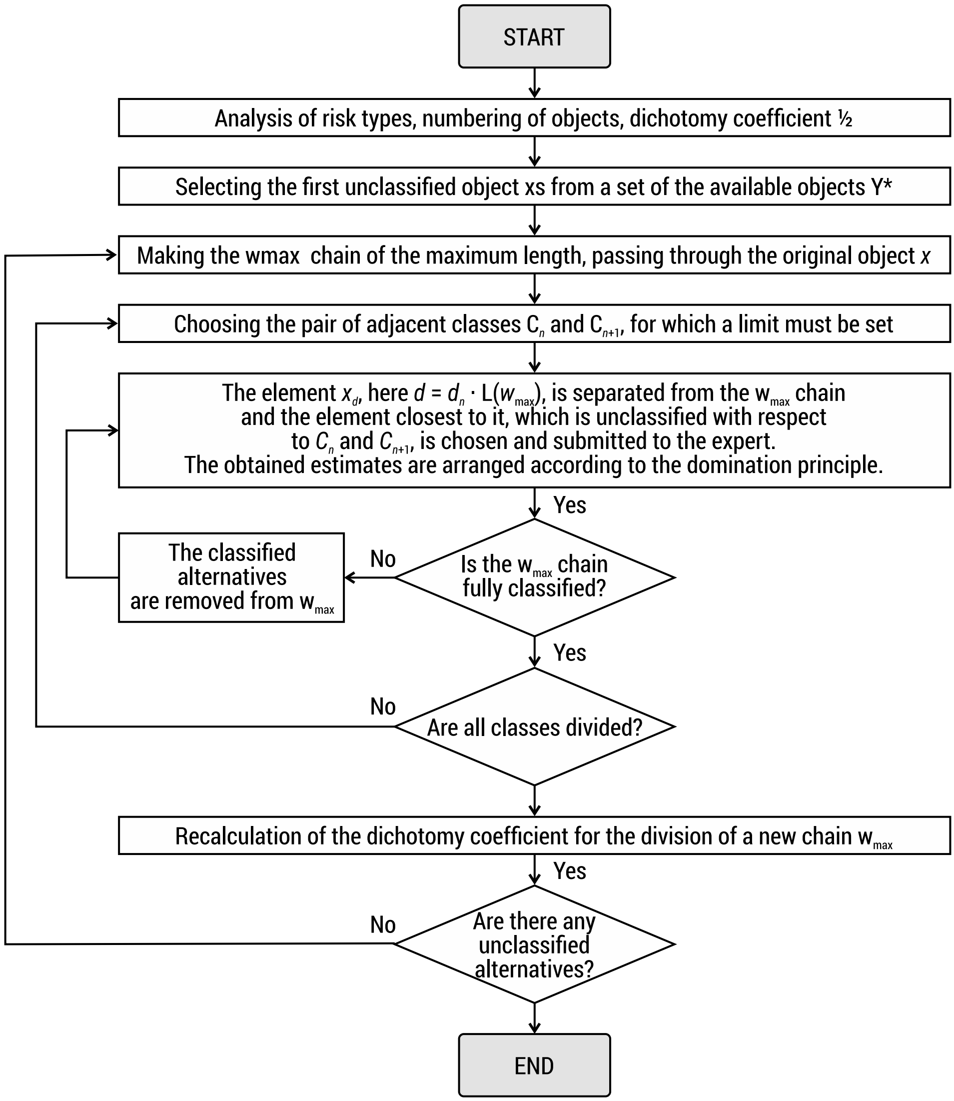


FIGURE 7.2. The algorithm of CLARA

Statement 1. If each statement is described by only two estimates arranged by properties and the number of decision classes is fixed, then the computational complexity of the CLARA algorithm does not exceed $O\left(\left|Y\right| log_2 \left|Y\right|\right)$.

Proof. The computational complexity of DOMINATE and SELECT_X does not exceed $O\left(\left|Y\right| M\right)$, that is $O\left(\left|Y\right|\right)$ for an endless number of solution classes. The computational complexity of COMPUTE_DN and UPDATE_DN does not exceed O(M). The computational complexity of MAXCHAIN does not exceed $O\left(\left|Y\right|+\left|E\right|\right)$. If each of the N criteria has a binary rating scale, then the graph $G(Y, E)$ is an N-dimensional hypercube with a known number of edges $N2^{N-1}$ (Emelevich, 1990). Since $2^N = |Y|$, the computational complexity of the MAXCHAIN algorithm will not exceed $O(|Y| log_2 |Y|)$. The complexity of the other steps of CLARA is less than $O(log_2 |Y|)$, which implies that the complexity sought from above is limited to $O(|Y| log_2 |Y|)$.

Elimination of *logical* inconsistencies from expert answers. When solving classification problems with the three or more solution classes using the CLARA method, logical errors and inconsistencies may occur during the expert survey. Mistakes can be caused by carelessness, expert fatigue, the complexity of the task at hand. For the resulting expert base to be consistent, the consistency of the expert's decisions must be continuously monitored during the classification.

Using the CLARA, KLANŠ, ORKLASS, and CIKL methods, the ability to detect errors in expert responses is based on this feature of dominance property, written in formula (2) as a condition for classification consistency. The dominant alternative cannot have a less appropriate decision class than the dominant one (Larichev *et al.*, 1989).

Let $Yx \subseteq Y^*$ be the set of alternatives immediately classified by the expert before the moment of the contradiction. If the consistency feature is not fulfilled for any pair of expert-classified alternatives, that is $\exists \boldsymbol{x}, \boldsymbol{y}_{\in} Yx$: $\boldsymbol{x \phi y}$, $\boldsymbol{x}_{\in} C_i$, $\boldsymbol{y}_{\in} C_j, i > j$. This indicates that the obtained expert answers contradict each other. Failure to meet the specified property can be explained by one of the following reasons: 1. there is an error in the known dominance relationship according to one or more criteria; 2. an incorrect the expert's answer when classifying alternatives.

If an error has been made regarding the dominance relationship, then the expert's interview must be repeated after correcting it, possibly using the available protocol of non-contradictory answers. If the expert has made a mistake in classifying the alternatives, the procedure for immediate correction of the objection applies (Larichev, Moshkovich, 1996). The pair is submitted to the expert for redistribution into classes when there is an objection in a pair of alternatives from $\boldsymbol{Y_X Y_X}$. This process lasts until all disagreements are resolved.

Unfortunately, such a procedure only clarifies severe logical errors in the expert's answers. Besides, it is valid only when the number of classes is not less than three. For a more subtle interpretation of expert errors affecting classification, special techniques are used, as described in the following section.

Comparison of order classification algorithms. The CLARA method, like other methods of verbal solution analysis, is designed to perform a complete (the term "complete" means assigning each possible alternative from Y^* to one of the classes, in this particular case) and consistent classification, minimizing the number of possible expert queries. The CLARA method needs to be compared to other methods to understand how this method copes with the task. Naryzhnyi (Naryzhnyi 1998) and Asanov (Asanov, 2002; Asanov, Kochin, 2002) propose a general scheme for the comparison of classification algorithms, which is convenient to apply to the evaluation of the CLARA algorithm.

Studies of the behavior of experts in solving classification problems show that their decisions can be well defined by the most important rules with a two-level tree structure (Larichev, 1994). The roots of the tree correspond to the conjunction of the values of some of the most important (main) features. The end vertices to the combinations of estimates specific to the class in question according to less significant criteria.

Suppose there are two classes of solutions: C_1 and C_2. Let N be the number of binary criteria; *r* be the number of principal criteria, and *t* be the number of first estimates by additional criteria, and $0 \leq t < (N - r)$. When alternative y has early estimates according to all *r* essential criteria and at least *t* according to additional criteria, it belongs to class C_1, Otherwise, it belongs to class C_2. The formulated rule is used as the basic rule by the expert in determining the number of expert requests required to form a complete classification with each of the algorithms under consideration. The average number of applications *Q (A, r, t)* of the algorithm *A* will be the average number of queries of the given algorithm among all possible main criteria of selection *r*, the number of which is equal to C_N^1. The necessity of the average of the options for the selection of the main criteria is determined by the sensitivity of the analyzed algorithms, the location of the main criteria among the remaining criteria.

For example, if $N = 4$, $r = 2$, $t = 1$, then there are two possible $C_N^1 = 6$ options for choosing the main criteria out of four, i. e., first and second, first and third, second and third, and so on. For each option, the number of referrals in the addressed algorithm is calculated, which is then averaged. The values of the number of oracle queries allow to characterize the compared algorithms to some extent. A more expressive assessment of their effectiveness can also be proposed, a measure of the excess of the number of questions asked in particular. Each class C_i is unambiguously defined by its upper range $B^U(C_i)$ and lower mode $B^L(C_i)$. Class ranges are the minimum set of objects that must be submitted to an expert (oracle) for a complete classification. In this way, it is convenient to take the size (from 3.1) of the efficiency indicator of the classification problem, an algorithm with two classes of solutions.

$$E(R, r, t) = \frac{\left|B^L(C_1)\right| + \left|B^U(C_2)\right|}{Q(A, r, t)} \quad (7.6);$$

where $B^U(C_1)$ and $B^L(C_2)$ are the upper and lower ranges of classes C_1 and C_2 respectively,

Q (A, r, t) is the average number of expert requests for known *r* and *t*.

The value of the algorithm efficiency indicator is always greater than 0 and less or equal to 1. It is a quantitative measure of the excess number of questions asked to the expert. For example, if the efficiency index of the algorithm is 1, then under the known *r* and *t*, the algorithm asks as many questions as are needed to form a classification. If the efficiency ratio is 0.5, then the algorithm asks two times more questions than are required for this particular case.

Different algorithms for order classification problems with binary criteria scales are compared in the article (Naryzhnyi 1998). The algorithms ORCLASS (Larichev, Bolotov 1996), KLANŠ, and several logarithms for deciphering the monotonic functions of algebraic logic were compared. DIFCLASS is overtaking other algorithms in terms of average efficiency. The KLANŠ algorithm does not descend much, apparently due to his orientation to a more general case in the scales of nonlinear order criteria. The methods of decoding monotonic functions (Sokolov, 1982), optimal according to Shannon, gave close results, achieving the maximum possible efficiency for the most complex functions and quite significantly lowering the DIFCASS algorithm at medium complexity.

The article (Asanov, 2002) evaluated the efficiency of the CIKL algorithm by comparing it with the A^* algorithm for deciphering the monotonic functions of algebraic logic (Aleksejev, 1976). Numerical modeling of the operation of comparable classification algorithms has shown that the A^* algorithm slightly (3–13%) exceeds the CIKL algorithm in the most complex (with the maximum number of elements), but in many cases lags behind the latter. For example, when $r = 3$, $t = 3$, the efficiency of the CYCLE algorithm is 5-10 times higher.

For an unambiguous comparison of the algorithms, let us determine the average efficiency $E_{ave}(A)$ of the algorithm as its efficiency $E(A, r, t)$, the average of which is determined from all possible combinations of r and t. The algorithm data (when $N = 11$, $Q = 2$) are shown in Table 7.3.

TABLE 7.3. The comparison of classification algorithms (Kochin 2007)

Algorithm	Number of references to the expert	Average efficiency
ORCLASS	265.08	0.33
DIFCLASS	148.54	0.67
KLANŠ	176.54	0.53
CIKL	146.63	0.68
A*	672.88	0.18

The leaders are KLANŠ and CIKL. KLANŠ is slightly less efficient, but its scope is more extensive, including a partial set of criteria scales and the possibility of classifying sparse space.

Evaluation of the efficiency of the CLARA algorithm. We will apply a typical efficiency evaluation scheme for the CLARA algorithm. To compare the CLARA algorithm with other order classification algorithms, we will perform statistical modeling of the classification under the same conditions, that is, in a binary problem with 11 criteria, $0 \leq t \leq 10$, $0 \leq r \leq 10$. Besides, since the CLARA algorithm is designed to solve, we will additionally model its operation in the case when the allowable set Y^* power is only 1/5 of the full potential of the alternative set Y^*. We obtain the data in Tables 14 and 1 below.

Thus, the CLARA algorithm appears as follows in the summary table of algorithm performance (Table 7.4).

As we can see, the CLARA algorithm is somewhat descending only to the CIKL and DIFCLASS algorithms. However, CLARA has applications in a much wider area, including the ability to operate with criteria scales of varying lengths (DIFCLASS only works with binary scales), with a partial range of scales, and also in heavily sparse spaces. CLARA is more efficient than the KLANŠ algorithm, which has the same scope.

TABLE 7.4. The table of comparison of classification algorithms (Ustinovichius, Kochin 2008)

Algorithm	**Number of references to the expert**	**Average efficiency**	**Number of references, when *P* = ⅕**
CIKL	146.63	0.68	–
DIFKLASS	148.54	0.67	–
CLARA	**159.88**	**0.65**	**69.90**
KLANŠ	176.54	0.53	76.89
ORKLASS	265.08	0.33	–
A*	672.88	0.18	–

After analyzing the presented CLARA method, it can be concluded that it provides a relatively simple solution to a wide range of tasks, including those in poorly structured areas. The method uses only qualitative information, and the final result, i.e., the evaluation of the alternative is presented in verbal expression. The possibilities of the practical application of this method will be reviewed in the next section.

7.6.1. Development of a verbal risk assessment model

When analyzing construction activities, the occurrence of risk is an integral part of this activity and all participants involved in it (Tamoshaitiene *et al.,* 2013; Zavadskas *et al.,* 2012; Paslawski, 2010; Ustinovichius, Shevchenko, 2008; Tamoshaitiene *et al.,* 2008; Ustinovichius *et al.,* 2008; Ustinovichius *et al.,* 2006). The risk can and must be managed to reduce the probability of adverse events, as has been mentioned in Chapter 2. But by analyzing the scientific literature (on companies and projects) on risk management (Pokrovksij, 2014; Majevskij *et al.,* 2013; Vaidogas, 2013; Turskis *et al.,* 2012; Zavadskas *et al.,* 2011; Zavadskas *et al.,* 2010a; Gracheva, Liapina, 2010; Ustinovichius *et al.,* 2010; Shevchenko *et al.,* 2013 and others), during the commissioned project and the research carried out ("Improving the quality management system in a construction company" Contract No. G-60/07)), it turned out that, in general, construction companies evaluate and manage only about 60 percent of investment projects and analyze possible investment alternatives. All risk factors when assessing and selecting contractors, suppliers, and other project participants. I. e., about 40 percent of non-quantifiable risks remain unevaluated and, as a consequence, unmanageable. The author of this paper would like to point out that the application of qualitative risk assessment methods in practice is quite complicated and often impractical, especially in medium-sized or small construction companies.

It is necessary to set goals, its solution model when starting to form a task. We create an algorithm for solving the desired goals to do this (Figure 7.3).

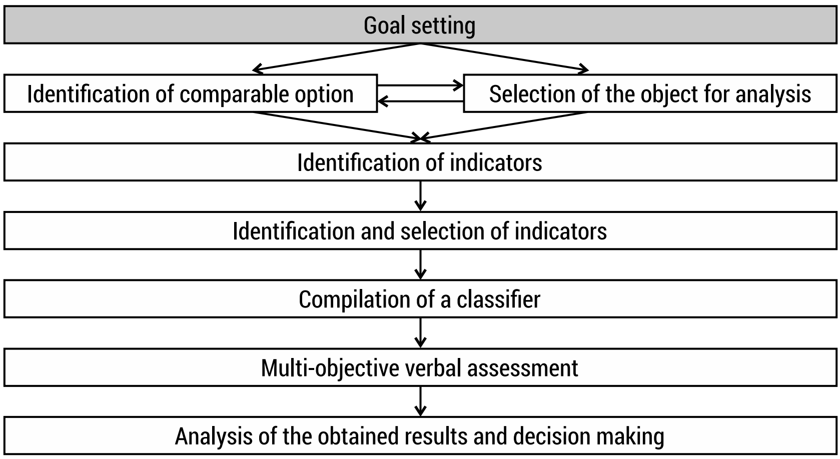


FIGURE. 7.3. Generalized algorithm of problem solving

When creating a risk assessment model for a company's investment decisions, firstly, we provide a review of the goals which are to be achieved, i.e., the stakeholders involved in this process are identified. In this case, the risk assessment of a construction company that is implementing an investment project risk assessment and of companies performing contractor functions is analyzed. This shows that it is necessary to assess all the possibilities for the proper performance of this type of company.

Having identified the needs, problems, goals of stakeholders, a task is being formed in which the problems raised should be solved.

The stages of developing a practical risk assessment model for a construction company are evaluated in Figure 7.4.

After evaluating all these stages, a practical model of risk assessment of a construction company is created (Figure 7.5). The possible risk assessment model of the company is implemented in the following main stages:

- Formulation of goals and objectives set by the stakeholders of construction investment activities. In this case, we examine the risk of construction companies by the investor (customer) point of view, i.e., the customer-contractor, the contractor-customer. In both cases, long-term cooperation aimed at the efficient operation of the company with the lowest level of risk is analyzed. Meaning, the company's risk optimization task is solved.

- Information is collected to solve the problem, and the research object is described. After selecting the research object (in this case, the construction contractor's or customer's company), an analysis of the situation is performed. It is found that the aspects evaluated by the researcher may vary (external: economic, social, ecological, etc. and only internal, or their complex).

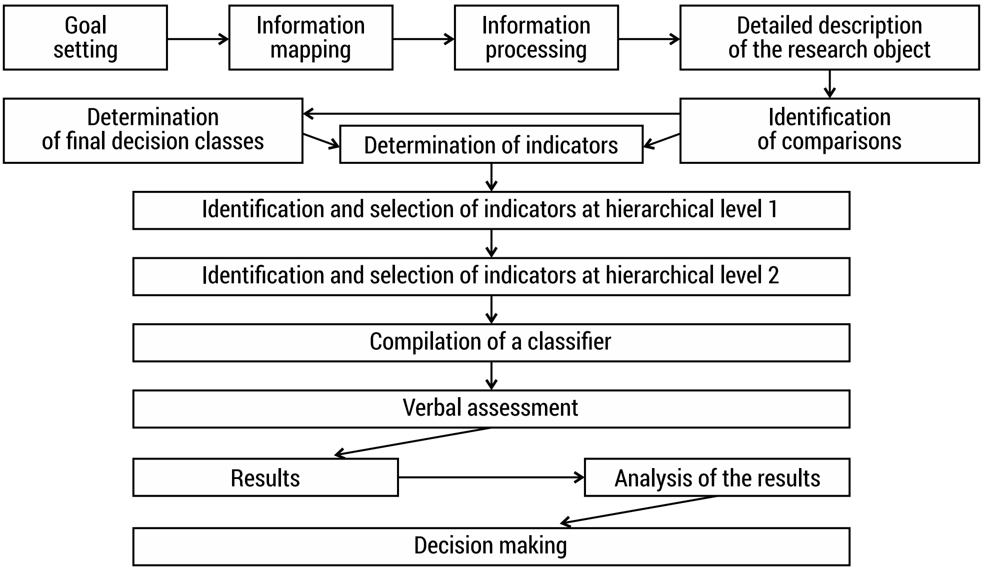


FIGURE 7.4. The basic stages of assessment model

After clarifying the objectives of the task, we identify the comparison options needed for the decision-making. Note that a risk assessment of one object can be performed to determine its risk level, in which case the comparison options are not selected, and all other stages of the model are applied to one object under consideration.

- Problem-solving. It is necessary to comprehensively assess all the internal and external indicators surrounding the company, to perform a detailed analysis of the research object, which reflect the aspects of the investment (construction) activity in question, and to determine the final class decisions. Thus, the last class decisions are determined first. The data needed to make a decision are presented in verbal form.
- Next step is the selection of indicators at hierarchical level 1. At this stage, the types of risks that affect the object and its activities mostly are selected. It is necessary to perform an elaborate analysis of the company's external and internal risks to carry out a detailed risk analysis. The needed data are presented in verbal form to make decisions.

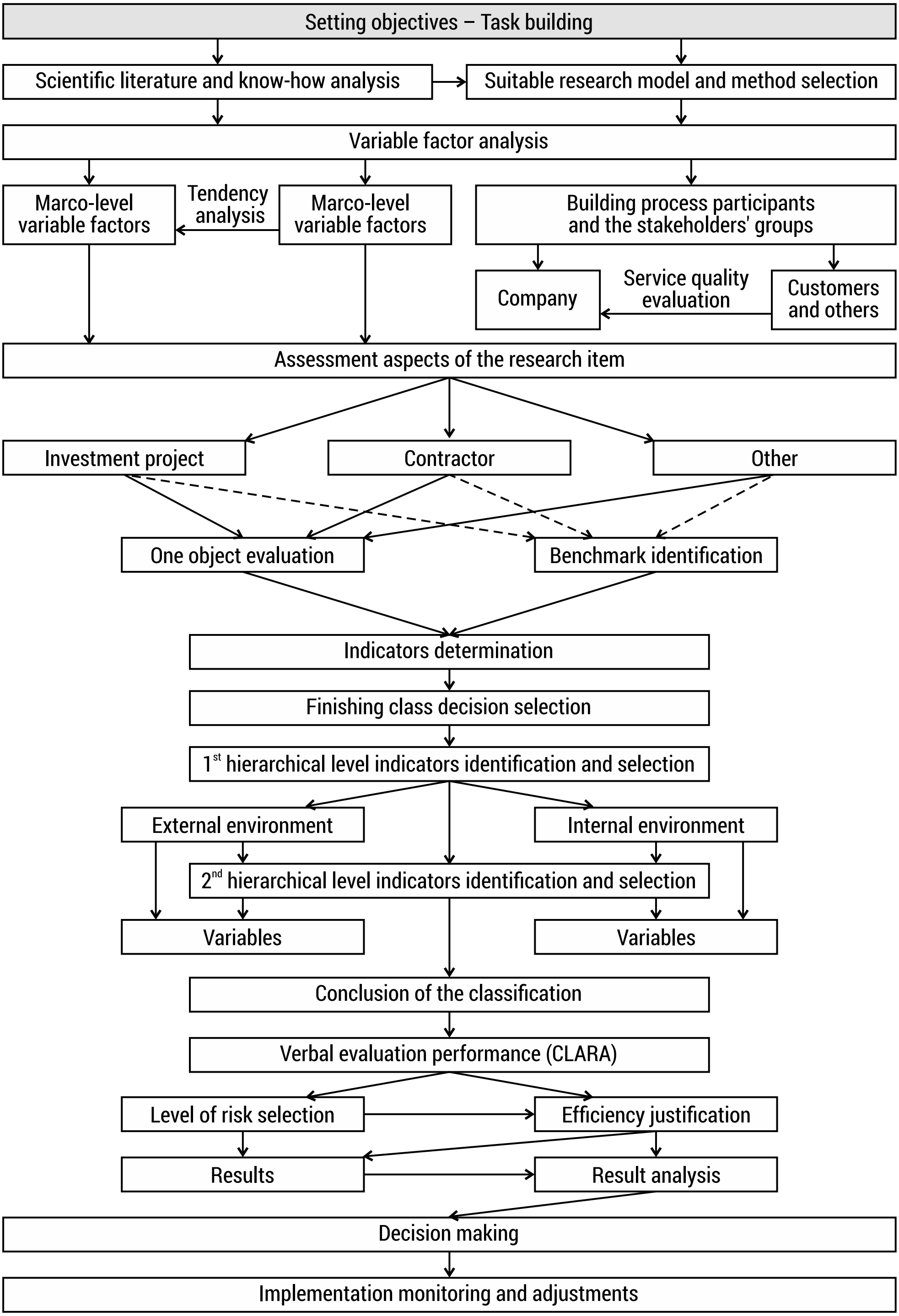


FIGURE 7.5. The complex enterprise investment decisions risk assessment model

- After creating the hierarchical level 1, the hierarchical (lowest) level 2 is designed. The criteria that make up the 2nd level of the hierarchy are also presented in verbal form.
- A risk classification of the company is developed, covering final class decisions, 1st, and the then 2nd hierarchy levels. The assessment choices are set in verbal (e.g., high, medium, low) form for the 1st and 2nd hierarchical level indicators. There is a possibility to increase or decrease the number of values according to the needs of the SPA.
- A verbal classification is performed after compiling the classification of risk indicators. In this case, the classification of real alternatives is realized by the CLARA method. At this stage, all the steps of the multi-objective decision-making method are performed.
- Conclusions are formulated after performing calculations, based on the obtained results. It is noticeable that in the case of more than one object, the results are compared with each other and the object. In this case – the project and/or the contractor's company is selected with the lowest level of risk.

7.6.2. Determining the risk level of construction investment projects by the verbal method

Classification is created to determine the risk of investment projects, which consists of risk assessment criteria and final class decisions (Figure 7.7). The risk assessment criteria for an investment construction project are presented at the first and second levels of the hierarchy.

When evaluating a construction investment project, the following shall be taken into account:

- Technical-technological risk;
- Construction risk;
- Financial risk;
- Political risk;
- Ecological risk;
- Legal risk.

} Criteria of the 1st hierarchy level (Figure 7.8)

The 1st level of the hierarchy is the main one. According to the criteria of this level, we can assess the risk of a construction investment project. Each criterion at this level is assigned with a rating: low, medium, high, or very high. After entering the ratings, we get the result, i.e., we determine risk levels (Figure 7.6).

These criteria alone (Level I) are not always sufficient to determine the degree of risk of a construction investment project. Therefore, each criterion at the 1st level of the hierarchy is divided into criteria at a lower level. This creates a 2nd level of hierarchy (Figure 7.9). Criteria of the 2nd level are required for a detailed analysis to be performed (each type of risk is analyzed).

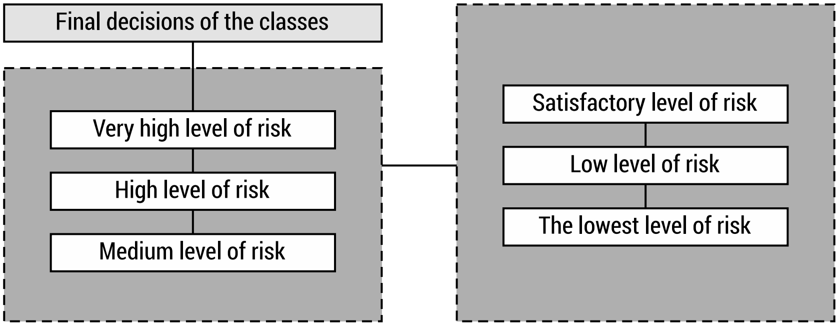


FIGURE 7.6. The risk levels (source: author)

According to the scheme, we get the following risk assessment workflow:

Second hierarchy level criteria assessments ⇒ first hierarchy level criteria assessments ⇒ risk level. Hierarchy level 2 consists of the following criteria:

- Skilled workforce
- Construction materials supply
- Design errors
- Construction workflow
- Transport problems
- Supply problems
- Product quality
- Management quality
- Insolvency situation in the construction
- Reduction of the project output price in the market
- Construction costs
- Resource price fluctuations
- Accidents
- Environmental requirements legislations
- Change of government attitude to the project
- Non-performance of contracts
- Inaccurate construction documentation
- Uncoordinated legislations
- Internal and external legal processes

The task of the work is to determine and compare the risk levels of two available investment projects.

It is possible to determine the level of risk using the established classification, but a vast number of criteria need to be compared. It's hard for a person to do that, and it takes a lot of time. Therefore, the computer program CLARA (classification of real alternatives) can be.

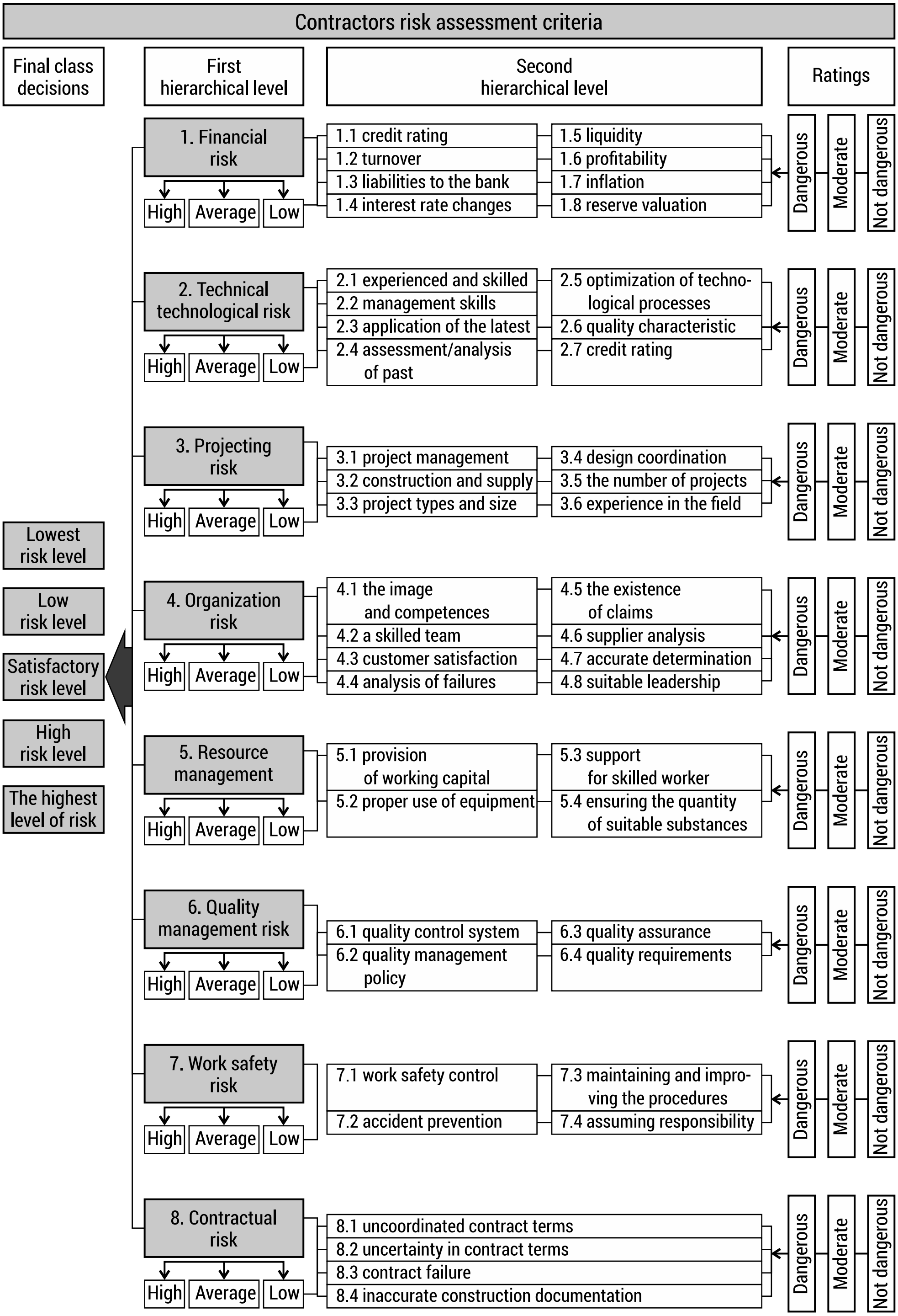


FIGURE 7.7. The investment risk evaluation classificatory (source: author)

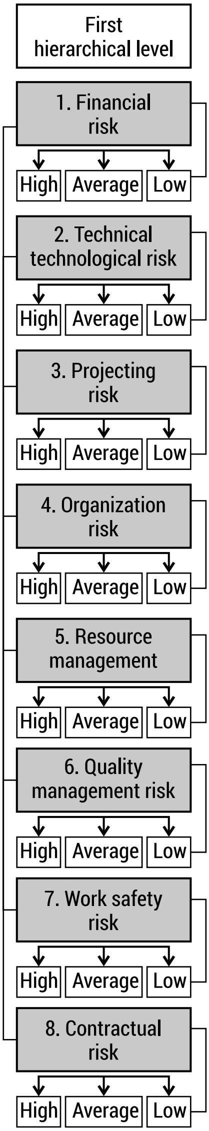


FIGURE 7.8. The first level of the hierarchy

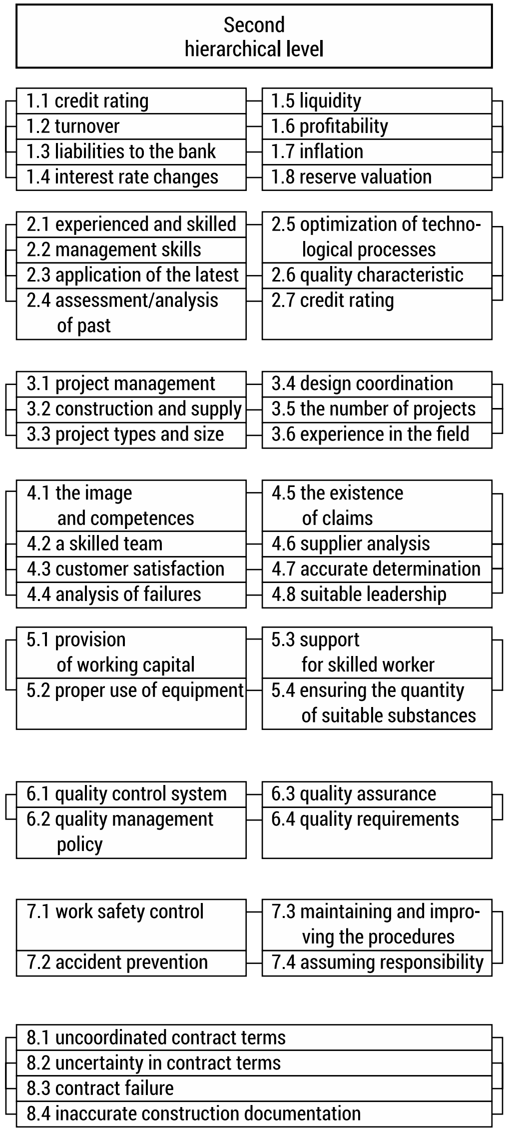


Figure 7.9. The second level of the hierarchy

7.6.3. Process of concluding the classification

Entering data into the program:

1 STAGE. Contractor company financial risk evaluation (Figure 7.10). Eight second hierarchical level evaluation criterion are inserted (Criteria 1 – credit evaluation; Criteria 2 – turnover; Criteria 3 – obligations to the bank; Criteria 4 – interest rate changes; Criteria 5 – liquidity; Criteria 6 – profitability; Criteria 7 – inflation; Criteria 8 – reserve evaluation).

Criterion evaluation classes: Class A – High; Class B – Average; Class C – Safe. Criterion 1 – 8 are chosen for contractor company risk evaluation.

While analysing the company (1 alternative) the expert determines if the company‘s taken credits and their the amount is not harmful for the company‘s performed tasks safety; if the company is able to account for the obligations to the bank; if the tasks turnover comply with forecasted indicators; if the company‘s financial indicators ensure the company‘s liquidity and profitability levels. After analysing the company‘s financial risk it is determined if there are no faults or contradictions in the classification.

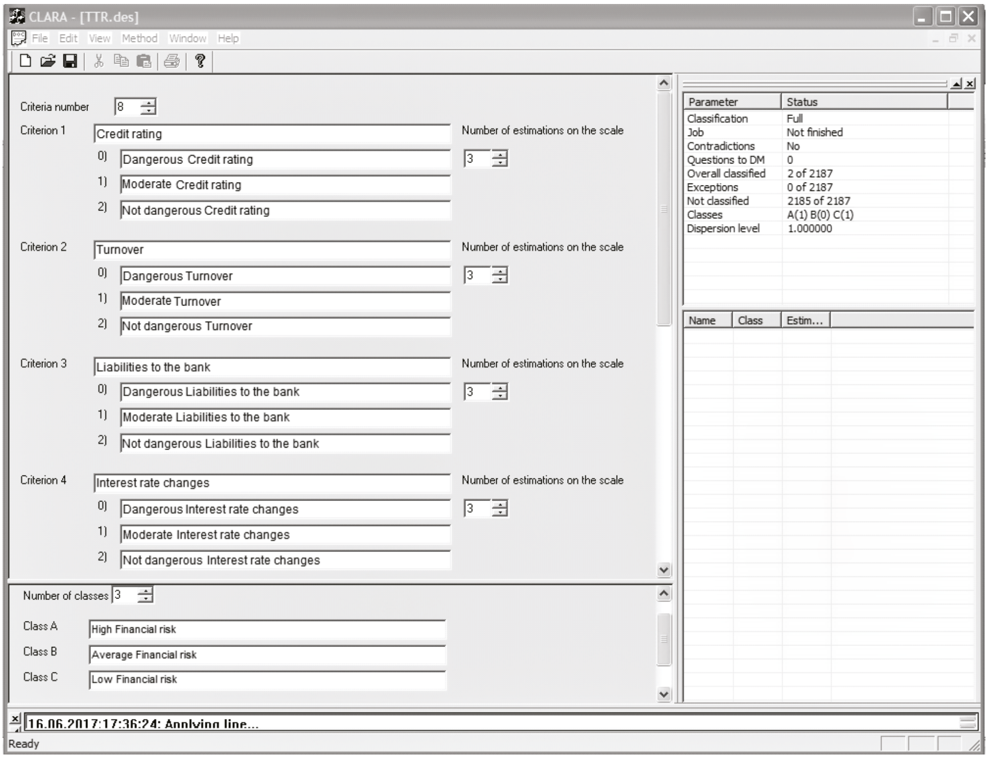


FIGURE 7.10. Financial risk assessment criteria of contractor

2 STAGE. Company‘s technical – technological risk evaluation (Figure 7.11) is combined from (criteria 1 – experienced and skilled workforce; criteria 2 – management skills; criteria 3 – application of the latest and most innovative technologies; criteria 4 – assessment/analysis of past factors; criteria 5 – technological process optimization; criteria 6 – quality characteristics/level maintenance; criteria 7 – project management structure strict responsibility level strips; criteria 8 – building and supply process assurance).

The data is inserted in the same way as in the first stage in the software. In this stage the company‘s technical- technological potential criterion are evaluated.

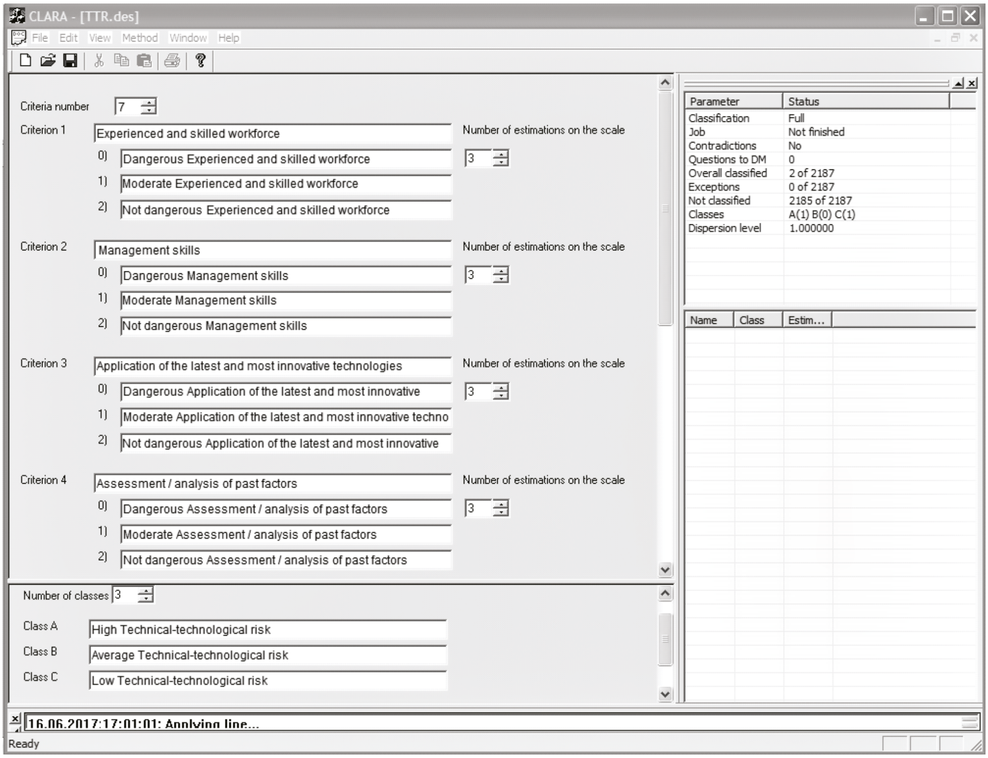


FIGURE 7.11. Technical-technological risk assessment criteria of contractor

All the leftover data is inserted into the software in the same way as in the first and second stages. After inserting all the data from 2 hierarchical level data then the 1 hierarchical level data is inserted (criteria 1 – Financial risk; criteria 2 – Technical-technological risk; criteria 3 – Projecting risk; criteria 4 – Organizational risk; criteria 5 – Resources management risk; criteria 6 – Quality management risk; criteria 7 – Safety management risk; criteria 8 – Legal – contractual risk; criteria 9 – Building risk).

After inserting risk verbal evaluation scheme data into the software the classification starts.

Classification process in the software. After inserting all the criterion according to which the company will be evaluated the last step is performed – the criterion are compared. Comparison (Figure 7.12) is performed in this way: the software chooses one of each criterion evaluation and creates their combinations. The expert attributes the given evaluation combination to a certain class. For example, if the software has this combination: (moderate – quality control system; moderate – quality management and risk management policy; moderate – quality and environment requirements maintenance; moderate – quality guarantee evaluation).

The expert attributes it to class B – average evaluation.

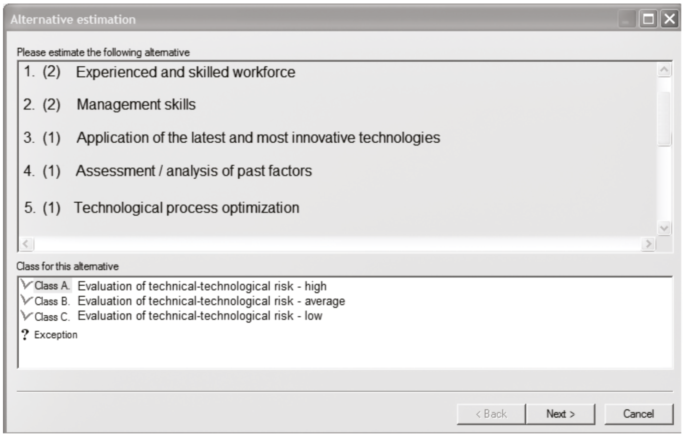


FIGURE 7.12. Assessment of alternative

After the attribution the next step is taking place (after pressing the button "NEXT"). Another evaluation combination is given. It continues until the moment when all the combinations are attributed to a certain class. In the process the expert may make mistakes and change his opinion and for that reason contradictions appear in the answers. In this case the software shows a warning that some contradictions appeared and asks to confirm the new answer or change it. After using the software CLARA all the contradictions are liquidated in the process.

After finishing the job the software saves all the data and performs an analysis which shows the number of SPA questions, how many combinations were made and how many of them were liquidated. It also shows how many evaluated combinations were attributed to the classes A, B and C.

In the same way all the second hierarchical level criterion evaluations are determined. In this case all ten files are analysed by using which the contractor company's risk level is determined.Evaluations are inserted into the software CLARA data base (Figure 7.13):

Company's financial risk evaluation consists of:

- credit evaluation – (1),
- turnover – (0),
- liabilities to the bank– (0),
- interest rate changes – (1),
- liquidity– (0),
- profitability– (0),
- inflation– (1),
- reserve evaluation – (1).

According to these results, after inserting them into the software, we see that the company's financial risk evaluation is **high – A class (risky)**. In the same way the company's technical- technological risk evaluation, projecting risk, company's organisational risk evaluation, resources management risk evaluation, quality management risk evaluation, safety risk evaluation, contractual and legal risk evaluation, company‘s building risk evaluation is performed. The data base is given below. It is connected directly to the criterionclassification in the software CLARA. The person who wants to determine the building investment project risk level has to insert the given evaluation of the experts into the data base.

Final solution analysis. The final analysis is performed according to the first hierarchical level evaluation (Figure 7.14). After performing the final analysis we get the company‘s evaluation results, i.e. the risk level is determined. We get five first hierarchical level criterion. Criterion evaluation classes can be seen in the picture:

Result: according to these results the company is attributed to the class B – low risk level.

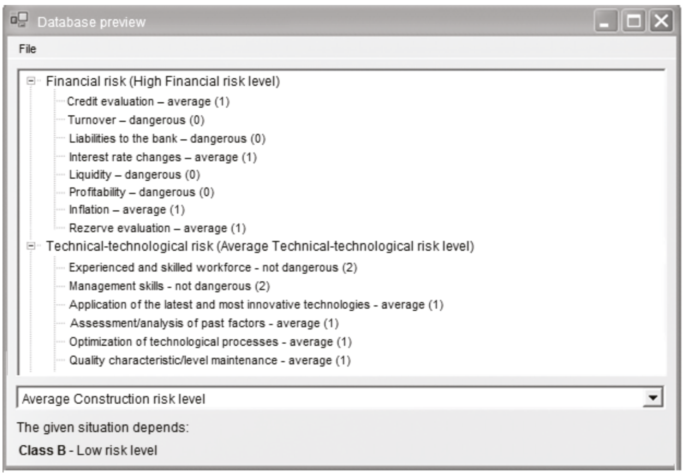


FIGURE 7.13. Data base (contractor company) criteria assessment

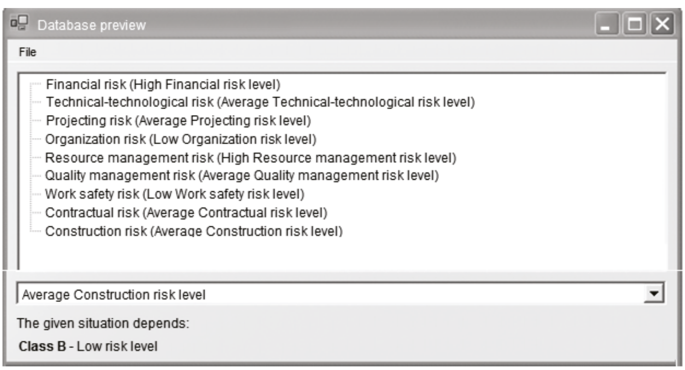


FIGURE 7.14. Data base (contractors I hierarhy level)

Conclusions. Scientific literature analysis established that many factors surrounding the activity / project must be considered assessing the risk: social, economic, political, cultural, and so on. New methods, capable to fully (complex) analyze the activity or project risk, must be applied and development.

The set of decision-making methods and techniques is created in the whole world. Many normative methods were introduced as “universal” methods, that is as the best (optimal) solutions. Their application in different areas of problems revealed the application insufficiency of the following methods: little reliable, complex usage, lack of alternatives.

Risk assessment and management in making investment decisions is one of the main success tasks. Project or contractor risk management is an integral part of project management and investment solutions assessment and justification.

The possibilities of the theory of verbal analysis for the contractor’s risk assessment and management were analyzed. It was found that verbal analysis methods may be relevant challenges in the less structured decision-making areas. These include risk assessment problems. The global experience analysis indicated that the proposed risk assessment methods do not allow to carry out a comprehensive companies’ investment decisions (projects) risk assessment and multi criteria (multipurpose) analysis that evaluate the indicators (criteria) described not only by discrete but also lexicographical values, therefore the article proposes the verbal analysis method CLARA for the problems’ solution.

Verbal analysis method CLARA acting on the basis of multipurpose classification. The proposed the real alternatives classification algorithm (CLARA) helps to create and actualize complete and compatible data bases that allow creating more efficient construction investment decisions conditions.

7.7. The implicit learning system

This outlines the main ideas for building an intelligent computer system educating the procedural expert knowledge, and the development of these ideas since the creation of the first such system. The system is based on the principle of implicit learning. The article describes the methodology for implementing these ideas in practice on the example of teaching the art of diagnosing acute myocardial infarction.

In many areas of professional activity, university education creates only the basis for the further development of a specialist. An aspiring engineer, doctor, or geologist has only theoretical knowledge, in contrast to mathematics, who can solve rather complex problems. The ability to solve practical problems is developed among engineers and doctors during many years of intensive practice. The nature of natural problems determines the long time required to achieve a high professional level, in which (unlike mathematics), there is no single correct way of solving, and the solution itself is subjective (Larichev, Brook 2000).

A specialist who has reached the highest level of skill in his professional field is usually called an expert. Research in cognitive psychology has shown that the journey from beginner to expert takes at least ten years of intensive practice. Interestingly, this period is approximately the same in such different branches of human activity as medicine, music, architecture, geology, and chess. During this time, not only does the amount of knowledge increase but its structure and the strategy of thinking itself change (Ericsson, Lehnmann 1996).

Studies for comparing the behavior of experts and beginners in solving diagnostic problems have shown significant differences in strategies for finding solutions (Patel, Ramoni 1997). It was shown that when solving a problem, beginners mainly use the so-called “inverse conclusion”, that is, they go through all possible solutions, while simultaneously searching for arguments in favor of each of them. It takes them a lot of time to complete these actions, and the solution obtained in this way turns out to be often wrong. Unlike beginners, experts use the so-called “direct inference”, that is, a direct transition from the description of the problem to its solution without enumerating numerous options. In contrast, the answer in the overwhelming majority of cases is not only fast but also correct.

The direct inference is a recognition process that can be modeled using a set of decision rules. However, the fundamental difficulty remains the impossibility of obtaining from an expert explicitly a system of decision rules that adequately describe his decision-making strategy. Usually, experts can formulate such rules only for the most simple and obvious cases [Larichev, Naryzhny 1999].

The non-verbalizing the expert decision-making strategies gives reason to believe that a significant part of his skills is at the subconscious level (Kihlstrom 1987). Studies of the mechanisms of mental skills show that the emergence and improvement of these skills occur in the process of intensive practice and depends on its duration. Although the student’s abilities are essential, the law of “10 years of practice” is universal (Ericsson 1996).

It is customary to distinguish between two types of subconscious (or implicit) skills (Berry, 1987). The mental abilities of the first type initially have an explicit, declarative presentation. Still, as a result of intensive practice, their application becomes automatic, which does not require a concentration of attention and reflection.

The subconscious skills of the second type are distinguished by the fact that even initially, they cannot be presented in an explicit, declarative form. The formation of such skills is possible only as a result of practice, which is an integral part of the implicit learning process in this case (Berry, Broadbent D. 1984, Reber, 1967).

Another characteristic of expert knowledge is its narrow focus. The experts behave like beginners outside of their professional field.

The duration of the formation of expert skills determines the urgency of the task of reducing this time by creating new computer technologies that can not only produce copies of expert knowledge in a computer but also effectively train young specialists.

The first such system that trains young doctors in the diagnosis of pulmonary embolism (PE) was the OSTELA system, created at the ISA RAS under the leadership of Academician O. I. Larichev (Larichev, Brook 2000, Larichev, Naryzhny 1999).

7.7.1. The targeted audience for the implicit learning systems

Insufficiently intensive practice increases the duration of the formation of expert skills. Therefore, first of all, implicit learning systems are intended for beginners and are designed to intensify training. For example, in medicine, doctors traditionally learn from their own experiences. And, before reaching an expert level in their field, they manage to make mistakes many times, and each mistake can lead to negative consequences when making decisions in practice. To reduce this factor, young engineers undergo long-term training under the guidance of experienced specialists, when the latter can correct their decisions.

Main ideas of the training system. It is necessary to solve two problems (Larichev, Brook 2000) to build a computer system that can teach a beginner the skills of an expert:

1. Build a knowledge base (abilities, skills) in a computer that accurately imitates the knowledge of an expert.
2. Training the beginner to solve practical problems in the same way as an expert does.

Building a knowledge base. The approach was developed (Larichev, Mechitov *et al.*, 1989) to solve the first problem, an expert classification, which allows creating a base of complete and consistent knowledge in own professional areas in a short time. This approach is intended for a range of tasks in which an expert assigns different objects to different classes of solutions (classification problems).

Let's consider the formal setting of the ordinal (ordinal) classification problem.

Data:

1. G – is a feature that meets the target criterion of the problem (the presence and severity of the disease, the critical malfunction of the technical system, the value of the credit project, etc.).
2. $K = \{K_1, K_2, \ldots, K_N\}$ – a set of criteria (features) evaluating each object of the research.
3. $S_q = \{k_1^q, k_2^q, \ldots, k_{\omega_q}^q\}$ for $q = 1,\ldots, N$ – is a set of estimates by the criterion K_q; ω_q – is the number of gradations on the K_q criterion scale; the estimates in S_q are ordered in descending order of specificity for property G. That is, on each set S_q, a linear reflexive, antisymmetric transitive relation Q_q is defined such that $\left(k_i^q, k_j^q\right) \in Q_q \Leftrightarrow i \leq j$.

4. $Y = S_1 \times S_2 \times \ldots \times S_N$ – is the Cartesian product of the criteria scales that determines the state space of the objects to be classified. Each object is described by a set of estimates according to the criteria $K_1,\ldots,K_N$, and is represented as a vector estimate $\boldsymbol{y} \in Y$, where $\boldsymbol{y} = \left(y_1, y_2, \ldots, y_N\right)$, y_q is equal to the number of the estimate from the set S_q.
5. $L = \left|Y\right| = \prod_{q=1}^{N} \omega_q$ – cardinal number Y.
6. $C = \left\{C_1, C_2, \ldots, C_M\right\}$ is the set of classes of solutions ordered in descending order of the severity of property G. That is, on the set C is a linear reflexive, antisymmetric transitive relation Q_C is defined such that $\left(C_i, C_j\right) \in Q_C \Leftrightarrow i \le j$.

The binary strict dominance relation:

$$P = \left\{ (\mathbf{x}, \mathbf{y}) \in Y \times Y \middle| \forall q = 1 \ldots N \quad x_q \ge y_q \quad \text{and} \quad \exists q_0 : x_{q_0} > y_{q_0} \right\}. \tag{7.7}$$

This is anti-reflective, asymmetric and transitive.

It is required: to construct a mapping F with the help of an expert: $Y \to \left\{Y_i\right\}$, $i = 1 \ldots M$, such that $Y = \bigcup_{l=1}^{M} Y_l; \quad Y_l \bigcap Y_k = \varnothing$, at $k \ne l$ (where Y_i is the set of vector estimates belonging to the class C_i), satisfying the consistency property:

$$\forall x, y \in Y : x \in Y_i, y \in Y_j, \left(x, y\right) \in P \Rightarrow i \ge j. \tag{7.8}$$

Thus, the classification problem is to distribute L objects over M classes of solutions. In this case, the classification is considered consistent if an object with a more specific set of criteria for property G cannot belong to the class corresponding to a lesser degree of manifestation of property G.

Initially, the expert, together with the engineer, develops a description of a professional area in the form of a set of features that characterize the analyzed objects and lists of possible values of these features. Then the classes of decisions are determined according to the severity of a particular disease. It can be several classes, differing in the severity of the disease or, in the simplest case, two classes, “the disease is”, “the disease is not.” The values of the signs are ordered according to the specificity of this disease.

In general, an expert is required to make a diagnosis (refer to one of the classes of solutions) to all possible hypothetical patients, their number is L, to build a complete knowledge base. However, with the characteristic values of the signs ordered by specificity, that is, in the case of an ordinal classification problem, more efficient procedures identifying expert knowledge, when a significant part of objects is classified indirectly, without presentation to an expert (Larichev *et al.*, 1989; Kochin *et al.*, 2002). In this case, *the dominance* relation (1) and the consistency condition (2) are used.

Along the way, with the classification, the expert's information is checked for random errors (consistency check), and the combinations of feature values that are impossible in reality are identified, which reduces the number of situations under consideration.

The constructed knowledge base can be described using *the boundaries* of decision classes consisting of non-dominated and non-dominant class objects – *boundary objects* in the case of ordinal classification (Figure 7.15).

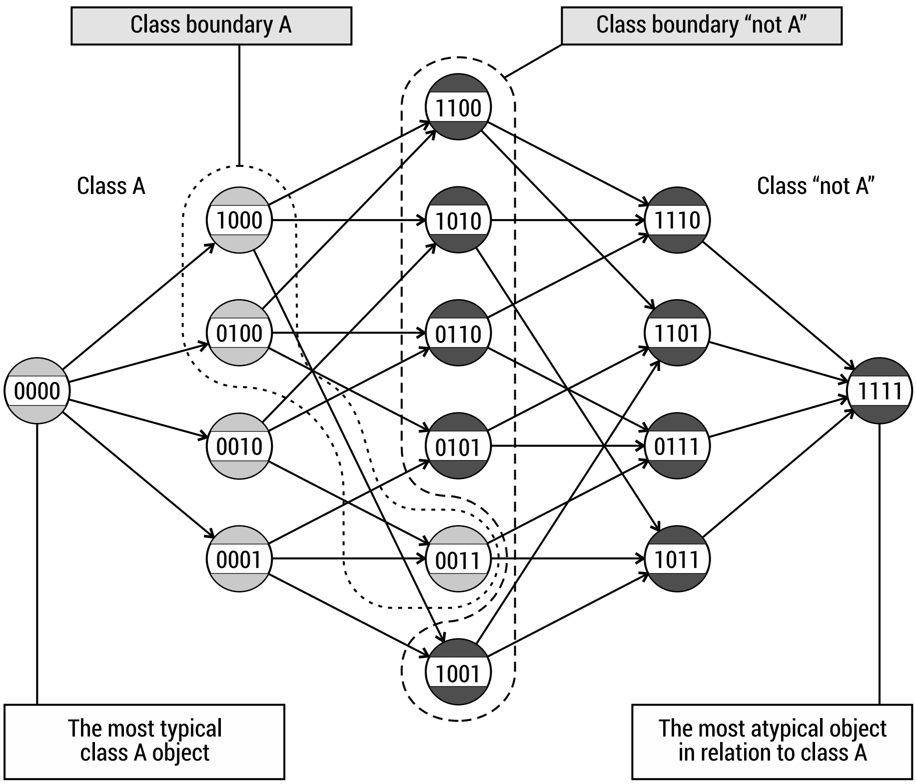


FIGURE 7.15. **Boundaries between solution classes in the problem of classifying objects described by four binary features**

An essential consequence of the introduced definitions is the fact that knowledge of the boundaries of a class of solutions is sufficient to describe the entire class. Therefore, it is enough to know only the boundaries between the classes of solutions to solve the classification problem.

The analysis of the boundaries between the classes of solutions showed that the behavior of an expert in classification problems could be modeled with high accuracy using a small number of decision rules that are relatively simple in structure (Larichev 1994; Asanov, Kochin 2002). Each such rule can be represented in the form of a tree, at the root of which are the values of the features most essential for the given class of decisions. A certain number of values of less important characteristics are added to them. Their additive nature seems necessary since the subconscious counting of typical values of slight signs is a standard operation performed by the human information processing system (Figure 7.16).

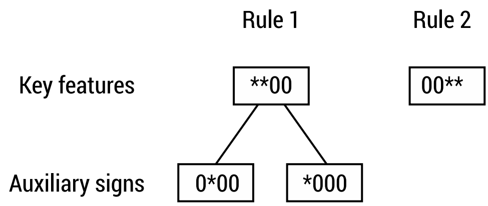


FIGURE 7.16. Rules for class boundary A in Figre 7.15

Figure 7.16 shows the decomposition into rules of the class boundary *A* shown in Figure 7.15. The '*' sign means "any estimate", while at the level of auxiliary characteristics, it can be specified what should stand instead of '*'. For example, rule 1 is formulated as follows: "if the values of the third and fourth features are *0*, and the value of the first or second feature is *0*, then the situation belongs to class *A*". Rule 2 – is formulated even more simply: "if the values of the first or second signs are *0*, then the situation belongs to class *A*".

A set of such rules describes a class boundary. By dominance, this rule applies to the entire class. Having the sets of rules for the lower-class boundaries, we get the rules for class separation. Herewith, to assign a specific situation to one of the classes, it is necessary to consistently check it for compliance with the rules for each class, starting with *A*.

The simplicity of the decision rules describing the expert's stable decisions made it possible to put forward a hypothesis that, as a result of many years of intensive practice, the expert forms subconscious recognition rules that are used by him in solving diagnostic problems.

Thus, as a result of building a complete knowledge base, we get a holistic view of how expert knowledge is organized. The obtained results are entirely plausible for the available information about the human information processing system. Decision rules are like "indexes" for the "knowledge encyclopedia" of an expert, allowing a quick search. Without a doubt, such indices are formed in memory in many years of intensive practice (Larichev, Brook 2000).

7.7.2. The implicit learning

After finding a way for a compact representation of the expert's knowledge, it becomes possible to solve the problem of effective teaching the art of diagnostics. The goal of the training is to create subconscious rules in the long-term memory of a young specialist that allows them to make decisions in the same way as an expert does.

The most obvious solution is to present decision rules to the trainee to memorize and then present tasks to consolidate the material. However, such a scheme, quite suitable for teaching typical problems of mathematics, turned out to be utterly helpless in teaching the art of diagnostics. It turned out that learning according to the explicitly formulated decision rules does not develop the trainees' skills of clinical thinking by an independent analysis of the presented description of the patient but comes down to routine logical and arithmetic procedures. The rules themselves are not always amenable to explanation despite their formal simplicity, although the solutions they describe are apparent to an expert. The optimality of the set of rules means that forgetting only a small piece of code causes negative results when passing validation tests.

The idea that there is no need to try to "pass on" the final rules of an expert to a trainee, but to help him to "grow" them on his own, using a person's capabilities for implicit learning (Reber,1967) appeared to be the way out of the impasse. For that, the trainees need to be presented with a series of problems without expert decision rules. This paradigm has produced exciting results. During the entire course of study (two days for four hours), each of the trainees, the cadets of the Russian Academy of Postgraduate Education, and novice doctors of the GKB im. Botkin solved about 500 problems of varying degrees of complexity. On the control test, the trainees demonstrated 90-100% coincidences with the expert's answers, but at the same time, they could not formulate the rules they used when making decisions like the expert. Some of them passed the second test a week later and gave 85-95% correct answers, which indicates the consolidation of the skill (Larichev, Naryzhny 1999).

It is important to emphasize that the proposed teaching method is based on the creative process of a student's analysis of his solutions and their comparison with the expert's solutions. In this process, the clinical thinking of trainees develops, helping to form a new, more profound view of the problem being solved in diagnostic.

7.7.3. Methodology

A simple presentation of problems is not enough for successful learning. A particular methodology is required allowing the training to be carried out most effectively. The experience of creating systems for teaching procedural knowledge made it possible to formulate the well-known "8 principles" of teaching methods (Anderson, Corbett 1995):

1. To simulate a trainee by a set of products.
2. To inform the trainee about the structure of sub-goals that must be achieved to solve the problem.
3. To conduct training in the context of real problems.
4. To help the trainee to abstract the knowledge gained in solving specific problems.
5. To minimize the load on short-term memory.

6. To provide an instant response to the errors of the trainee.
7. To change the detail of the subject area depending on the success of the training.
8. To allow to master the individual components of the skill.

In practice, not all of these principles have been successfully implemented. Besides, a priori, not every subject area, allows the implementation of all these principles.

The methodology used in the teaching system has the following essential features:

1. Theoretical course. This course is necessary, first of all because teaching practice is impossible without knowledge of the theory, and secondly, it helps the student to "enter" the subject area model.
2. Presentation of real, everyday tasks, if possible. Such a selection of tasks makes the training system closer to the process of real accumulation of experience by an expert. Besides, it increases the student's interest in the system.
3. A consistent complexity increase in the tasks presented, depending on the progress of the trainee. The way of breaking down tasks into difficulty levels will be described below.
4. Indicating the trainee mistakes and explaining the correct decision. This allows to improve the memorization of tasks significantly and makes learning more enjoyable.
5. Control of the cognitive process. This builds a model of the trainee keeping track of the mistakes he makes and identifying "gaps" in his knowledge. Training can only end if there are no gaps in knowledge left.

The learning process goes as follows. The trainee passes a monitoring test that reveals the current level of his knowledge, evaluating it by the percentage of correctly solved problems. Then he goes through a theoretical course, refreshing his memory of the main features of the subject. After that, he is consistently presented with situations for which he must independently choose one of the proposed options. If the answer is incorrect (that is, if the answer does not coincide with the expert's), the training system shows a comment similar to the expert's explanation of his decision. With the successful solution of a certain number of tasks, the system increases the level of their complexity, with a large number of errors, on the contrary, decreases them. The training ends when the student learns to solve problems of the highest level of complexity confidently. In the end, the trainee takes another control test to record the improvement in the practice of the decision problem. Let us consider in more detail some of the components of the technique.

Identification of the complexity of tasks. An expert creates his own implicit decision rules throughout his life, facing the various tasks in his subject area. Moreover, it goes from simple to complex in most cases. It is also logical to make the training system so that at the beginning of training, a student is presented with the more straightforward tasks, gradually moving on to more complex ones as the material is mastered.

Formally, the complexity of problems can be determined based on the distance between the case described in the problem and the boundaries of neighboring classes of solutions. As a result, the full set of situations is divided into layers of varying complexity (Figure 7.17), with the least complex cases far from the boundaries, and the more complex ones close. The most difficult situations, both for the trainee and the expert, are located directly at the border (Larichev, Naryzhny 1999).

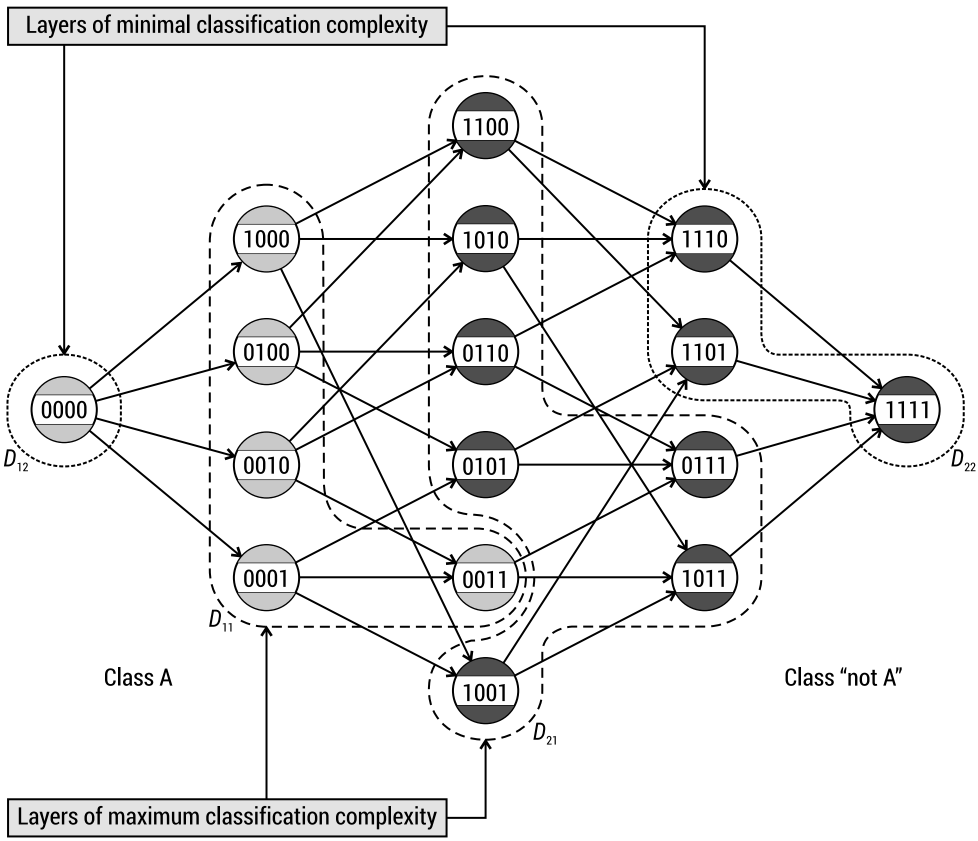


FIGURE 7.17. Layers of varying complexity for classification

The formal method of dividing into difficulty levels by distance to the border does not always work in practice. This is because different signs have different importance for the diagnosis. Therefore, some tasks have to be manually transferred to a more complex or more accessible level of complexity.

A compilation of real tasks. In the process of building a knowledge base, situations that are impossible in reality (with conflicting values of signs) are already eliminated. The established knowledge base will contain only possible situations. However, often some of the situations in this database, although suitable for creating an expert consulting system, is still not ideal for training.

The experts are distinguished by their "direct" and quick problem solving, as mentioned earlier. However, when constructing knowledge bases, it was noticed that in complex cases, rarely encountered in practice, experts can use a "reverse" strategy, that is, reasoning. The situation may be difficult for an expert, also because it is shown in the form of a model, and the expert may not have enough information. Besides, many cases have been described in the literature when experts were mistaken "under the influence of the latter case" (Bordage 1999). Thus, each expert can have a zone of "unstable knowledge", which can lead to distortion and complication of decision rules, which negatively affects learning (Figure 7.18).

Moreover, it makes no sense to teach unstable knowledge, since the instability is caused by the doubts of an expert, that is, by the controversy of the situation. The problem is in separating unstable from stable knowledge. A hypothesis of the expert not keeping the rules for dividing classes in his head but the rules for assigning a situation to a specific class, in particular, is put forward. This hypothesis is tested by conducting two classifications on the same set. At the same time, the first classification focused on the first-class; that is, the classes of solutions were – "class A" and "everything else." In the second case – "class not A" and "everything else." At the same time, a thin layer of presumably unstable situations formed between classes A and non-A.

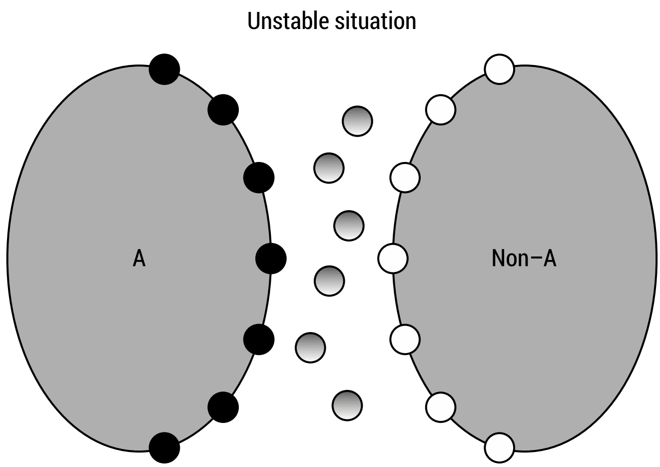


FIGURE 7.18. Instability of knowledge of class boundaries.

Stable expertise can be more accurately determined using this binary classification following this hypothesis. However, this area still requires more detailed research.

Interpretation of the trainee mistakes. Learning is not sufficient without explanation of the mistakes made by the trainee when solving the wrong task. Therefore, for each wrong answer, the training system must provide some account of the expert's answer. Unfortunately, due to the non-verbal decision rules, the expert is not able to give an exhaustive explanation of why he solved the problem in this way. However, when teaching, too detailed explanations are not required. It is enough for the trainee to point out the principal values of the features that led the expert to such a decision. The expert can explain such a plan explicitly, and this does not cause any particular difficulties.

Moreover, effective teaching practice is impossible without knowledge of theory. Therefore, the training system should indicate the sections of the textbook that contain information for solving such problems together with the comment.

Material acquisition control. The learning process must be controlled to adapt it to the abilities of the individual trainee. The first OSTELA training system [Larichev, Brook 2000] managed the quality of mastering the material as a whole. That is, the training system counted the number of errors made, and it switched to a lower level of problem complexity when a specified maximum number was exceeded. However, the practice has shown that tasks for some decision rules are easy for trainees, while for others, it is more complicated.

Therefore, a method was proposed for controlling the assimilation of individual rules in the new system of implicit learning MI. In this case, the student moves to a higher level of complexity only after he has learned to solve problems that meet all the rules. Moreover, at the end of the system, more smooth assimilation of the material is provided.

The presented work outlines the main ideas for building an intelligent computer system for expert knowledge teaching procedures and the development of these ideas since the creation of the first such system.

Such training systems can be used both for training young specialists and for additional training of experienced specialists in other fields. They can acquire diagnostic skills close to the capabilities of experts in this area of knowledge in a shorter time and at the lower cost of fatal mistakes.

New computer technologies create new conditions for the appearance of a new type of university education – training a young specialist with both theoretical knowledge and the ability to solve practical problems.

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