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Overview of Multi-attribute Decision-analysis Tools for Selecting Investment Options in Municipal District Heating Systems

Dominika Dawiec*, Grzegorz Ginda**

Abstract. Municipal district heating systems in Polish cities constitute important elements of these municipalities (and not only of their technical infrastructures). Due to the nature of the basic service that is provided – providing heat (and perhaps year-round comfort in the future) – these systems can be perceived as important parts of the social infrastructures of the cities, creating the appropriate conditions for the existence of people, the functioning of social infrastructure facilities, and the operations of enterprises. The need for heating companies to adapt to any changes in the requirements that arise as a result of the economic, social, environmental, and (increasingly) political and legal changes that take place in its immediate and distant environment requires the implementation of investments. However, the effects of such investments are multidimensional and largely difficult to measure; they depend on the passage of time and complex conditions that are related to the pursuit of sustainable development and security. Their reliable assessment therefore requires the use of appropriate tools. This paper is devoted to an analysis of the practical usefulness of multi-attribute decision-analysis tools in this context, taking various types of such tools into account as well as the conditions for their effective applications. The most promising of these tools is also introduced and discussed.

Keywords: thermal energy, city investment, decision, assessment, multi-attribute analysis, technique, review

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1. INTRODUCTION

Due to climatic conditions, a *municipal district heating system* (MDHS) is a typical element of the infrastructures of every Polish city. Their task is basically to provide heat during the multi-month heating season, ensuring appropriate living conditions for the populations and the functioning of enterprises and other institutions that operate in the cities. It is worth paying attention to the fact that the heating systems of Polish cities are currently obligated to perform an important function that is related to environmental protection in some fashion. This involves helping to reduce the low emissions and pollution that are generated by outdated individual heating devices that are fired with fossil fuels. *Ustawa z dnia 10 kwietnia 1997 r. Prawo energetyczne* [Polish Energy Law Act of April 10, 1997] (1997), imposes an obligation to connect consumers to heating networks whenever possible.

The existence of buildings that are still not connected to heating networks and the appearances of new potential heat-collection places due to city development result in a need for making the investments by the companies that manage the networks. The complex nature of such investments requires the prediction of various investment scenarios and a multidimensional assessment of their potential effects. Local and global conditions mean that the effects of such investments are influenced by many factors of various natures: political, economic, social, technical, environmental, and legal. Such effects may also be difficult to measure, and information regarding their determinants is often imperfect. Therefore, it is worth using the possibility of structuring the issues of developing heating networks for their proper holistic approaches thanks to the use of the PESTEL framework analysis (Political-Economic-Social-Technical-Environmental-Legal analysis) (Walsh, 2005). The multidimensional nature of potential investment effects means that their rational assessment requires the use of specific tools that take this fact into account. Many tools are provided by the decision-analysis methodology (Goodwyn & Wright, 2014) – especially its multi-attribute approach (MADA – multi-attribute decision analysis). Due to the richness of the MADA tools, these will reviewed in this work; also, we will take the availability of their computer implementations into account as well as their applications for solving the decision-making issues that are related to urban thermal energy. On the basis of this review, the best tool will ultimately be recommended.

The second part discusses the basic types of MADA techniques. The third section is devoted to their current applications in urban thermal energy. The conclusions on the suitability of techniques for assessing and analyzing any investment alternatives were finally presented.

2. MULTI-ATTRIBUTE DECISION ANALYSIS

Numerous (often very extensive) studies have been devoted to the MADA methodology (Greco et al., 2016; Ishizaka & Nemery, 2013; Trzaskalik, 2014). Basically, this methodology involves an analysis and assessment of the adopted decision making alternatives of action (decisions) that are the subjects of certain decisions and described

by a specific set of parameters (attributes). Following Roy (2016), it can be stated that there are four basic applications of MADA:

1) describing issue under consideration (P.δ problematics);
2) choosing (most appropriate) decision option (P.α problematics);
3) grouping (similar) decision decision making alternatives (P.β problematics);
4) ordering (ranking) decision making alternatives (P.γ problematics).

Let us note that, while the last three types of problem are intended for specific actions on a set of decision alternatives, P.δ pursues a specific goal of enriching the analysis of the considered decision-making issue; this may allow the implementation of one of the other issues in the future. What is also noteworthy is the possibility that different types of MADA issues may be considered after one another. For example, a previously determined ranking of decision making alternatives can be used for selecting the appropriate decision making alternative; when selecting or ranking decision making alternatives, the result of their previous grouping can be used, etc.

To solve specific problems that are related to the P.α, P.β, and P.γ MCDA applications, numerous MADA tools have been developed. Based on the principles that they utilize, these can be divided into four groups (Greco et al., 2016; Ishizaka & Nemery, 2013):

1) full-preference aggregation techniques;
2) outranking relation-based techniques;
3) aspiration- and reference-level techniques;
4) specific techniques based on other foundations.

Note that the most popular MADA techniques belong solely to the first three groups.

2.1. Full-preference aggregation techniques

The idea of the full aggregation of preferences is related to the concepts of multi-attribute value theory (MAVT) and multi-attribute utility theory (MAUT) that were introduced by Keeney and Raiffa (1976). This involves the use of a weighted, additive, or multiplicative aggregation of the partial preferences of decision-making alternatives to evaluate them. Due to the place of the origin of this idea, this is called the American school of decision analysis.

One of the most commonly used tools that directly implements the above idea is simple additive weighting (SAW), which uses additive formulas. This also has a much-less-popular multiplicative counterpart – in the form of simple multiplicative weighting (SMW).

When it comes to more-complex techniques, Saaty's AHP (Analytic Hierarchy Process) is the most popular one (Saaty & Vargas, 2012). It seems that, apart from its universal nature, the basic reason for such a position is its use of a simple evaluation mechanism (i.e., pairwise comparisons), thus facilitating the use of imperfect information and the simplicity of the calculations and structuring of decision-making problems by using the hierarchical relationships between the components of the problem model. The methodology (proposed by Saaty) also allows one to take the more-complex two-way relationships between the model components into account. This is achieved by

replacing the hierarchical structure of their connections with a network structure that is used by the network equivalent of AHP in the form of ANP (analytic network process) (Saaty & Vargas, 2011). An important advantage of the above techniques is the availability of software that fully supports the implementation of complex analyses. For example, one can use a computer application called *SuperDecisions* to facilitate advanced AHP analyses of complex decision-making cases. This software is available for free at https://www.superdecisions.com.

Among the remaining tools for the full aggregation of preferences, those techniques that improve the methodology that is used in the AHP technique stand out. These include the MACBETH technique (Measuring Attractiveness by a Categorical-Based Evaluation Technique) (Bana E Costa & Vansnick, 1994) and REMBRANDT (Ratio Estimation in Magnitudes or deciBells to Rate Alternatives that are Non-DominaTed) by Lootsma (1992). Because of their more complex nature, however, their use is only possible through the use of specialized software (unlike the original).

Summarizing the subject of those techniques that use the idea of a full aggregation of preferences, it can be said that their main purpose is to organize and rank decision making alternatives. These techniques also have a compensatory nature that consists of the possibility of improving the overall assessment of a decision making alternative that is inferior to another decision making alternative in terms of certain attributes thanks to the advantage of the result from a better assessment in terms of its specific attributes. It is worth noting that this feature of the techniques is not welcomed when looking for the global-best-decision alternative.

2.2. Outranking relation-based techniques

The superiority relationship allows one to identify cases of the type of domination of individual decision making alternatives over other decision making alternatives. In order to determine whether this actually occurs between decision making alternatives that are compared within a pair, the detailed relationships that correspond to the clear advantage of one decision making alternative over the other (preference relationship), the identity (indistinguishability relationship), and the incomparability (incomparability relationship) of the compared decision making alteratives are usually used. Due to their European origins, these techniques make up the so-called European school of multi-attribute decision support.

Basically, two basic families of techniques can be distinguished in this group (Brans & De Smet, 2016; Figueira et al., 2016): ELECTRE (ELimintion Et Choix Tranduisant REalité), and PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation). It is true that there are many other available techniques that use the idea of superiority relationships, but they are derivative in nature. Both families of techniques consist of numerous technique alternatives, which, unlike those techniques that use the idea of a full aggregation of preferences, offer not only the possibility of ranking but also grouping decision alternatives and a direct recommendation of the most appropriate one among them.

The techniques of the ELECTRE family are based on the direct comparison of decision making alternatives in the context of their partial assessments (expressed in

the levels of their attributes). At the same time, it is possible to use various mechanisms to prevent a too-hasty acknowledgement of the advantage of one decision making alternative over the other in doubtful cases; these include the preference, indistinguishability, and veto thresholds. The final decision on the detailed relationship between the compared decision making alternatives is made on the basis of the relationship between two indicators: compliance (concordance index), and noncompliance (disconcordance index). It should be noted that the use of the pairwise comparison mechanism by the families of the ELECTRE techniques facilitates also includes the possibility of a direct comparison of the decision making alternatives in the context of those attributes that are difficult to measure.

In the case of the PROMETHEE family techniques, comparisons of decision alternatives do not rely on their attribute levels; the differences in their attribute levels are used for this purpose. To reduce all of the partial evaluations of any decision making alternatives to a common denominator, these differences are expressed in values that are within a mutually closed interval $[0, 1]$. The transformation of the absolute value of the difference into a number from the unit interval is performed by using a specific unitarization formula, which can take various forms (both continuous and discontinuous [stepped]) while also taking the threshold values of the preferences and veto into account. The concept of a weighted preference flow is used to determine the forms of the detailed relationships that connect the decision making alternatives. In the case of a specific pair of decision making alternatives, this may take a positive form (positive preference flow), whose results stem from a partial advantage over the second decision making alternative, and a negative form (negative preference flow), whose results stem from a partial advantage of the second decision making alternative. The PROMETHEE family of techniques is also equipped with an advanced graphic tool – GAIA (Geometrical Analysis Interactive Aid) – which is designed for interactive visualizations of analysis results.

Due to the tedious nature of the analyses and calculations, the use of superiority relationship techniques requires computer support; fortunately, software is available to implement such techniques. A good example of such a tool is the attractive (not only visually) Visual PROMETHEE application (available at: http://www.promethee-gaia.net/phone/visualpromethee.html). This tool was developed by B. Mareschal – the principal researcher who was involved in the process of the actual development of the PROMETHEE technique.

2.3. Aspiration- and reference-level techniques

Among tools of this type, two techniques are worth paying special attention to: TOPSIS (Hwang & Yoon, 1981), and VIKOR (Opricović, 1990). They use the idea of aspiration and reference levels by using pairs of abstract objects: a pattern (ideal), and an anti-pattern (anti-ideal). The basic advantage of these techniques (and the main reason for their popularity) is the use of geometric interpretations of the similarities between objects. They use a specific representation of decision making alternatives in the form of points in a multidimensional space of their attributes. As a result, this allows one to express the similarity of decision-making alternatives (also in relation

to the pattern and anti-pattern) using the distance of the points that represent them. Moreover, these techniques do not require complex calculations.

The names of both techniques clearly reflect their basic purposes. In the case of the first one (known as the technique of ordering decision making alternatives based on the similarity to a pattern – Technique for Order Preference by Similarity to Ideal Solution – TOPSIS), it is about ordering (ranking) the decision making alternatives. In the case of the second one – the multi-criteria optimization and compromise solution VIKOR (VIseKryterijumska Optimizacija i kompromisno Resenje), compromise-based indication of the most appropriate alternative or multiple most appropriate decision making alternatives.

The ordering of decision making alternatives in the TOPSIS technique is based on a specific metric that uses Euclidean distances of points that represent the decision making alternatives in a multidimensional space of appropriately normalized attributes from the pattern and anti-pattern. VIKOR operates on non-standard values of the attributes of the decision making alternatives. Three specific rankings are used to indicate the most appropriate decision options. The technique takes the possibility of using a veto from unfavorable attributes and the related sensitivity analysis into account. The technique also ensures that the ultimately recommended decision making alternative or variants show significant advantages over the other decision making alternatives.

There are also other tools that use the idea of aspiration and reference levels. For example, Konarzewska-Gubała (2009) proposed the BIPOLAR technique in this context, combining some features of the reference-level methodology and the ELECTRE family techniques.

2.4. Remaining techniques

Based on the works of Trzaskalik (2014) and Greco et al. (2016), three groups of other techniques can be distinguished: interactive, verbal, and those that use decision rules and specific representations of imperfections in any available information. Due to their complexity, the use of any of the above techniques requires computer support.

Interactive techniques have been developed to solve complex and insufficiently defined problems under conditions of imperfect information and, therefore, require the gradual discovery of knowledge about them. Basically, they are used to evaluate and select decision options. For this purpose, they use a multistage interaction with the decision-maker, which includes a repeated repetition of two phases. The first involves updating the information thanks to a dialogue with the decision-maker, and the second involves calculations that use the acquired information. There are several tools that implement such ideas; e.g., STEM-DPR (Nowak, 1992).

Verbal techniques are based on the idea of VDA (verbal-decision analysis). These techniques only use qualitative verbally expressed assessments of decision-making alternatives. Due to its use, it is possible to solve the issues of selecting and grouping decision-making alternatives. To accomplish the first of the above tasks, for example, one can use the ZAPROS LM technique (Russian: Метод ЗАПРОС – ЗАмкнутые

ПРоцедуры у Опорных Ситуаций) by Larichev and Moshkovich (1997) or the second one by the ORCLASS technique (Ashikhmin & Furems, 2005).

Among the techniques that use decision rules and a specific representation of imperfect information, the dominance-based rough set approach (DRSA) by Greco et al. (2002) stands out. It can be used to solve diverse problems: the selection, ranking, and grouping of decision making alternatives. Interesting analysis possibilities are also provided by the family of techniques called stochastic multi-criteria acceptability analysis (SMAA) by Landhelma and Salminen (2010). These involve exploring the space of the weights to determine those preferences that correspond to the specific positions of individual decision making alternatives in their ranking. The approach is applied in several stages; the individual stages serve to gradually expand the available information thanks to more-accurate measurements or determining the preferences of decision-makers, for example. The final decision is only made at the stage when the available information resources allow it.

3. APPLICATION OF MADA METHODOLOGY IN MDHSs

Below is a brief review of several dozen cases of applications of the MADA methodology in urban thermal energy, which were identified on the basis of the literature review. For this purpose, the *Scopus* bibliographic database was primarily used (https://www.scopus.com).

3.1. Full-preference aggregation technique use

AHP dominates other approaches that implement the idea of a full aggregation of preferences. The technique was also used to consider various contexts of sustainable development. For example, Wang et al. (2019) assessed the effectiveness of private-public partnerships in terms of investments in clean sustainable district heating systems. Laktuka et al. (2021) attempted to assess the degrees of attention of regional and local strategies to increase the efficiency of heating and cooling in the aspect of intensifying sustainable urban development, and Balode et al. (2021) proved the advantage of district heating systems over individual heating systems. Pellegrini et al. (2019) classified potential technical solutions that could facilitate the transformation of district heating systems into sustainable systems.

The AHP technique has been also used to evaluate geothermal district heating systems (Eltez et al., 1999), demand-side investment-management programs (Lee et al., 2007), and the engineering value of various configurations of systems that provide heat and cooling through the use of seawater heat pumps (Shu et al., 2010).

This technique also turned out to be an appropriate tool for supporting the optimization of the locations of heating plants (Geri et al., 2018), the energy-efficiency of a heating system (Skiba et al., 2021), and a system that integrated a heating network with an energy network (Arslan et al., 2021). In the last case, the use of AHP was skilfully combined with the TOPSIS technique.

In addition, this technique proved to be effective in solving the problem of selecting an appropriate heat source for a heating system (Dytczak & Ginda, 2006;

Fang & Wang, 2014). It was also used – together with GIS (geographical information system), a Bayesian network, and data-envelopment analysis (DEA) – to jointly implement a balanced-score chart (BSC) that supported the strategic management of a heating system (Bazil et al., 2021).

In turn, Bilić et al. (2020) used the SAW technique for a multi-attribute assessment of the suitability of geothermal waters in the context of their use, among others, for heating purposes.

3.2. Outranking-relationship technique use

The use of outranking-relationship techniques in urban thermal energy is represented by the ELECTRE and PROMETHEE techniques. The first was used by Grujić et al. (2014) to determine appropriate heat sources for Belgrade's district heating system, and Mróz (2008) applied it to plan a district heating system. Ghafghazi et al. (2010) applied it to assess the suitability of heat sources in a scenario-based approach. Fang and Wang (2014) used it – together with AHP – when selecting a proper heat source, and Ziemele et al. (2014a) used it – together with TOPSIS – during a scenario-based optimization of heating-system control.

3.3. Aspiration and reference-level-technique use

Among the techniques that use aspiration and reference levels in the context of urban thermal energy, the TOPSIS technique is dominant. At the same time, it is the most frequently used tool. By far, most of the applications of this technique concern the optimization of integrated systems that produce a combined heat and electricity output (Arslan et al., 2021; He et al., 2019; Wu et al., 2022), a subsystem of a heating system (Wu et al., 2020), a network that was powered by heat from two energy sources (Zhao et al., 2021), devices that were intended for heating systems that supplied heat to residential areas (Wu et al., 2021), the share of industrial waste heat and energy that was supplied by heat pumps to a heating system that would result in an effect that was close to carbon neutrality while reducing costs (Yuan et al., 2021).

Further applications of TOPSIS have concerned technological issues; in particular, assessments and selections of heat sources for municipal heating systems. As part of this topic, a multi-scenario assessment was carried out, and selections of technologies and heat sources for a municipal heating system were made (Boran, 2013; Polikarpova et al., 2019), an assessment of technologies used in heating systems was carried out (Streimikiene & Balezentiene, 2014), and an analysis of a cogeneration energy system that supplied a network was carried out, and its appropriate shape was recommended (Cimdina et al., 2014). The technique also supported an analysis of energy-transformation issues; this included determining the structure of a zero-emission heating system in the sense of avoiding the need to acquire greenhouse gas-emission allowances (Ziemele et al., 2016) and determining a target energy source for a heating system that operated within a local government unit (Prodanuks & Blumberga, 2018).

The use of this technique has also facilitated solutions of issues regarding sustainable development in heating systems. For example, Siksnelyte-Butkiene and Streimikiene (2023) assessed selected European countries in terms of sustainable development of the heating industry. For this purpose, multi-scenario analysis was used. On the other way, Prodanuks and Blumberga (2018) drew attention to the fundamental impact of the development of heating systems on the formation and development of urban energy plans, and Laktuka et al. (2021) – additionally supported by the AHP technique – carried out an attempt to assess the degree of attention that was paid in regional and local energy strategies to the potential for intensifying the sustainable development of cities by increasing the efficiency of their heating and cooling. However, Abokersh et al. (2021) addressed the issue of supporting the process of popularizing NZEB (near-zero-energy buildings) using solar district heating systems (SDHSs). Finally, a study determined the appropriate scale of an SDHS and proved its useful role in achieving sustainable development goals thanks to the use of a machine-learning model that integrated multi-criteria optimization with multi-attribute decision analysis. In turn, the additional – parallel – use of the VIKOR technique and several other tools allowed Wen et al. (2021) to prove the environmentally friendly nature of district heating systems as an energy source for Danish households.

In addition to the joint use of the technique that was mentioned with AHP to implement the BSC idea (Bazil et al., 2021), it has also been proven to be useful in other contexts of district-heating-system management. For example, TOPSIS was integrated with PROMETHEE in order to support the search for the optimal control mode of a heating system that supplied new buildings (Ziemele et al., 2014a), and the technique itself was used to support the reduction of pollutant emissions that were generated by a heating company due to the appropriate structuring of the thermal energy tariffs, thus promoting an increase in energy efficiency and the use of renewable energy sources in a heating system (Ziemele et al., 2014b).

3.4. Use of other techniques

Among other techniques, the SMAA technique has been used in urban thermal energy. Kontu et al. (2015) applied it to indicate an appropriate heat source for a planned estate of single-family homes, which ultimately turned out to be a heating system that produce heat from biomass in combination with electricity. Kirppu et al. (2018) used it for a multi-attribute assessment of zero-emission (i.e., carbon-neutral) heat-generation technologies. Wang et al. (2018) utilized the technique for an multi-criteria stochastic assessment of heating systems, while Pinto et al. (2019) used it to evaluate carbon-neutral technologies for district heating systems.

From the point of view of the subject matter that is considered in this work, an isolated case of using SMAA to evaluate alternatives of potential investments in an urban heating system (Wang et al., 2017) deserves special attention in the context of practical applications of the MADA methodology.

4. CONCLUSIONS

Contemporary decision-making problems in district heating systems are very complex, as their solutions are influenced by many specific factors; e.g., their multi-disciplinary nature, involvement of numerous stakeholders, multi-dimensionality and difficulty in measuring (at least some) assessment criteria, goals, and interactions with the multi-dimensional environment, and uncertainty as to the nature of their conditions in the future. Solving them cannot simply rely only on intuition, as this requires complex analyses. Fortunately, the MADA methodology has provided many different tools to support such analyses.

The literature review on the applications of MADA in urban thermal energy shows that, despite the much-earlier and long-term availability of mature techniques, interest in these applications has been relatively recent in urban thermal energy (only since the turn of the 20th and 21st centuries). Moreover, most of their applications concern the last few years and the following problems: the assessment and optimization of urban heating systems, the selection of the appropriate technology (including sources of heat), and the implementation of sustainable development and energy transformation. Some of the applications have also concerned the management of a district heating system and an enterprise.

In practice, the tools that represent each of the two types of MADA techniques that were distinguished at the beginning of this section were used for this purpose. These tools include TOPSIS (which represents aspiration- and reference-level tools) and AHP (which represents a full aggregation of preferences). Among the other more frequently used techniques, the following stand out: PROMETHEE (in the group of outranking relationship techniques), and SMAA (in the group of the remaining techniques).

Only in one of the applications – regarding the use of the last of the above-mentioned tools – the context of assessing and selecting investments in urban heating systems appeared directly. However, the nature and practice of using other MADA tools suggest the possibility of also using more-intuitive tools from other groups for this purpose, including the AHP, TOPSIS, and PROMETHEE techniques (and especially the underestimated tool – the VIKOR technique – which skillfully complements the methodology of aspiration and reference levels with a type of analysis sensitivity and the concept of veto). In turn, if it is necessary to take non-hierarchical multi-directional connections between various factors that determine the assessments of decision making alternatives into account, it is possible to use an improved variant of the AHP technique (in the form of ANP).

Ultimately, it can be concluded that the MADA methodology still has a lot to offer in the context of supporting the analysis of the complex investment variants that are implemented in urban heating systems – especially since there are also numerous possibilities of combining various tools. For example, if it is necessary to supplement quantitative techniques (such as tools that use aspiration and reference levels or SAW with the possibility of taking factors that are difficult to measure into account – safety, comfort, social mood, etc.), it is worth using the possibility of reliably processing expert opinions by using pair-comparison techniques; e.g., AHP or ANP. It is also

worth using a similar option in the case of objectifying the weights that determine the importance of the individual dimensions of investment analysis, which has been provided by several recent works (Arslan et al., 2021; Bazil et al., 2021; Fang & Wang, 2014; Laktuka et al., 2021; Ziemele et al., 2014a). An interesting potential solution that will enrich the analysis of investment variants may also be the use of a specific type of sensitivity analysis thanks to the concurrent independent use of various MADA techniques during the analyses of investment alternatives; e.g., Wen et al. (2021).

It is also worth noting that an undoubted advantage of the MADA methodology with regard to the analysis and selection of investment alternatives in municipal district heating networks may be the wide availability of their computational implementations that were extensively presented by Ishizaka and Nemery (2013) – especially in the case of using more-complex and more-advanced techniques.

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Use of Quick Response Quality Control (QRQC) Method in Process of Problem-solving – Case Study

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Abstract. This article presents an assessment of the use of the QRQC problem-solving method in the production-line area of a selected enterprise. This method was used to comprehensively solve the problems that could be observed in various areas of the company's operation, including quality, safety, and logistics. Based on literature research, the literature was analyzed and criticized, the researched method was characterized, and the principles on which it was based and the levels of its application were presented. The stages of the implementation of the QRQC method as well as the participants and their roles in the problem-solving process were presented. Then, a survey questionnaire was developed using the diagnostic survey method, and research was conducted among a representative group of operators who worked on the production line in a company that had been using the QRQC method to solve production problems for many years. The research made it possible to assess the functioning of this method in the studied enterprise, determine its advantages and disadvantages, assess the employees' understanding of the rules, the ease-of-use of the method, and the support that was received from the management during the entire QRQC process. The research results will allow the company to make mature decisions regarding the use and improvement of the functioning of the QRQC method. The conclusions from the study can be used by other companies that use this method or want to use it in their problem-solving practices in an effective and efficient manner.

Keywords: QRQC, problem solving, continuous improvement

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1. INTRODUCTION

Nowadays, company are facing various challenges such as higher product and service quality, shorter lead times, and increased competition (Antony et al., 2023; Skalli et al., 2023). In such a complex and changing environment, merely focusing on efficiency and costs is not enough – striving for perfection is becoming more and more important. The occurrence of problems on many levels seems obvious, so an important element of an enterprise's activities is continuous improvement and focusing on the process of solving problems that may occur (both inside and outside the enterprise).

Over the years, companies have developed many tools and methods for solving problems. The most popular tools that have been used in this area include the Five Whys method and the Ishikawa diagram. These are used in many comprehensive approaches for solving problems; the most popular of these include lean manufacturing (and the A3 Report that is related to this approach (Liker, 2004)) as well as Ford's Global 8D method (*8D – Problem Solving in 8 Disciplines. Method. Process. Report*, 2018; Soliński, 2019).

Although it is not as popular as those that are mentioned above, another method that is used to solve problems is the Quick Response Quality Control (QRQC) method.

This method was created and implemented in 2002 at Valeo – one of the leading suppliers of parts in the automotive industry. Its comprehensive characteristics can be found in (Aoudia, 2012; Aoudia & Testa, 2012). The QRQC method is a method for solving problems that arise in various areas and at various levels of an organization, such as a production-line area, a department, or the entire plant. Its name is an acronym that was created from the first letters of the phrase – Quick Response Quality Control, which can be translated as quick response – quality control. The main goal of this method is to solve the problems that can be observed in a given area of a company's operation, including quality, safety, and logistics. It focuses on a quick identification, analysis, and solution of the problem.

It integrates certain elements of methods such as Seven Questions (5W2H), Five Whys, PDCA, or Global 8D (Deming, 2000; Imai, 2012; *Six Sigma Blog: Sigmology*, 2022) and supplements them with process integration and cascading mechanisms for solving problems at several levels of the company and practice that allows for a significant minimization of its problem-solving time.

2. CHARACTERISTICS OF QRQC METHOD

The QRQC method is based on several theoretical foundations, such as the zero defects principle, the Jidoka system, and the Japanese philosophy of San Gen Shugi (which is often called the philosophy of three realities or three dimensions: San – three; Gen – real, current; Shugi – philosophy, dimension).

The first two are widely described in the literature on the subject (Liker, 2004; Womack et al., 1990). The zero defects principle was formulated by Crosby (1988) and consists of striving to eliminate all errors through the appropriate staff motivation, communication, and cooperation among the employees. The Jidoka system (Liker, 2004; Ohno, 1988) involves designing the process as well as the machines and people

that/who are involved in it in such a way as to prevent errors by quickly detecting errors and immediately stopping a process.

The third of these (San Gen Shugi) includes the following:

- The actual location (GEN-BA) where a problem occurred. Performing an analysis at the location of the defect allows for the proper assessment of a situation.
- Actual parts (GEN-BUTSU). This statement means how to handle any affected parts. The good and bad parts are reliably compared to an established standard.
- Actual data (GEN-JITSU). The analysis that is undertaken should be based on objective data and not on opinions or assumptions.

The QRQC method was designed to ensure quality in the production area. It can be characterized as a method of quick and comprehensive problem-solving that ensures finding the root cause, and the actions that are taken within it should guarantee that the problems will not reoccur in the future (Banica & Belu, 2019). QRQC is a tool for quick responses to problems (mainly of a qualitative nature) that occur in an enterprise (Teczke & Obora, 2018). According to its creators, it is defined as a philosophy of action that is closer to total quality management (TQM) than it is to other problem-solving tools that are used in the automotive industry (Global 8D method, Report A3) (Aoudia & Testa, 2012). QRQC was first used by Valeo in 2002.

This is based on six basic principles that organize and rearrange the process of its use (Aoudia & Testa, 2012):

1) *Quick response* – the method assumes identifying the problem as quickly as possible and solving it equally quickly.
2) *Specific people* – problems should be solved by people with appropriate knowledge and skills in solving them and conducting analyses.
3) *Concrete Object* – This refers to one of the three principles of reality in San Gen Shugi. The analysis should be performed on a specific tool or part.
4) *Specific area* – solving a problem should take place where it occurs.
5) *Specific data* – reliable verified documentation should be used during the problem-solving process.
6) *Logical thinking* – solving problems should be based on the logical reasoning of the problems and combining facts and cause-and-effect events.

The principles that are listed above are nothing new in quality-management systems and methods; together, however, they create a comprehensive approach that is characterized by effectiveness and efficiency and allows for quick results and significant benefits.

3. LEVELS OF PROBLEM-SOLVING ACCORDING TO QRQC METHOD

The main goal of the QRQC method at each level of a company is to detect a problem or defect, protect the customer, respond quickly, collect data, verify compliance with standards, keep a history of events, solve the problem, and (if necessary) explain the problem. The end result is solving the problem and drawing conclusions for the future as well as possible changes in the methods of conduct that allow for the continuous

development of the organization. The problem-solving takes place at three levels; these are presented in Table 1.

Table 1. *QRQC levels – source: own study based on Aoudia and Testa (2012)*

QRQC levels	Level characteristics
Line QRQC	Its scope includes the smallest production unit in an enterprise, which is called the autonomous production zone (APZ). The people who are involved in this process are the operators and the leader. They take action to immediately correct a problem that has been detected in their area of work. The time that is allocated for the entire QRQC process (i.e., from its detection to the rectification of the problem) is a maximum of 24 hours.
Department QRQC	Its scope covers the problems of many autonomous production units (APZ). These problems are more global in nature, affecting a larger group of production units as well as internal and external stakeholders (these concern warranty returns that are reported by customers and the failure to achieve the planned organizational goals, among others). The team that is responsible for solving the problem consists of specialists from various areas of the company's operation (e.g., quality, production, and logistics). As in the case of Linear QRQC, this diverse interdisciplinary group of people theoretically has 24 hours to complete the process; however, this goal is often not achieved due to the complexity of the problem.
Company QRQC	Its scope covers problems from various areas of the plant that affect the functioning of the entire production company. Teams are created and involve managers and other people who are responsible for individual departments of the company.

If a team that is working on a production line is unable to solve the problem at their own level, the problem may escalate. Passing the problem higher up in the company hierarchy can be done at two levels: the first of these is departmental QRQC; if the problem has not been solved at this level, the next stage is to transfer it to the next level (which is company QRQC).

4. QRQC AT PRODUCTION-LINE LEVEL

The described methodology is implemented at various levels in a production company, such as areas of the production line, department, or the entire plant. The entire process is carried out based on forms that are adapted to individual areas. The QRQC application process includes key activities such as the following:

- problem detection,
- standardization of reaction rule,
- internal communications and escalations,
- troubleshooting,
- inspections of completed activities.

Due to the research that is being carried out at the production line level, the procedure at this level when solving problems using the QRQC method is described below. The linear QRQC scheme is based on four stages (Fig. 1):

1) detection,
2) communication,
3) analysis,
4) verification.

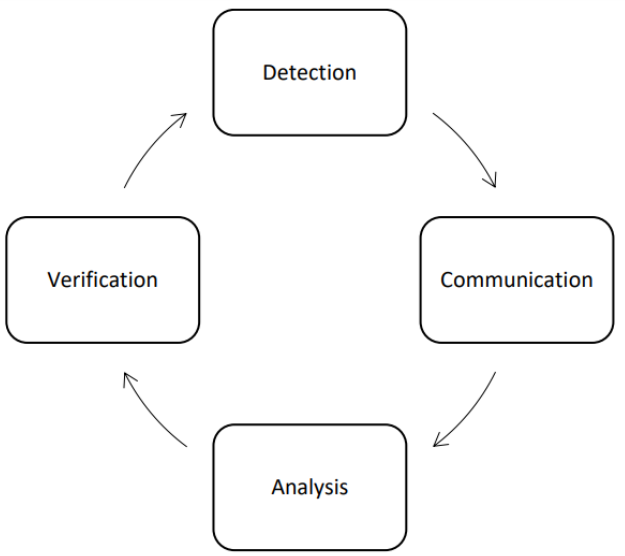

Fig. 1. *Operational diagram according to Line QRQC method*

Stage 1: Detection involves identifying a problem and determining the actual situation. The problem is categorized into one of the following categories: safety, quality, failure, logistics, or process efficiency. In order to standardize the descriptions of the problems, the seven-question method (5W2H) is often used, which allows for an objective presentation of the problem.

Stage 2: Communication assumes the provision of information about the problem to all interested parties. Additionally, immediate actions should be taken to protect internal and external customers at this stage. An example of such an action may be sorting pieces into those that meet the specification (OK) and those that do not meet the specification (NOK).

Stage 3: Analysis includes an analysis of the source of the problem and the formulation of the corrective actions. Using the Five Whys tool, it is possible to find the root cause of the problem. As a result, the proposed corrective actions concern a specifically defined cause of the problem. The person who is responsible and the estimated time for implementing a given corrective action are both defined.

Stage 4: Verification is focused on verifying the completed activities. The responsible person checks whether the proposed and implemented actions have had the intended effects. At this stage, it is also marked whether the problem has been escalated to a higher level and that the analysis is closed.

As described above, the QRQC method at the line level allows one to comprehensively address a problem in four steps – from its occurrence to its elimination.

5. CHARACTERISTICS OF CONDUCTED STUDY

The research was conducted in August 2022. The data was collected using a direct survey questionnaire among the employees in one of the automotive industry enterprises where the QRQC method has been used for many years. The survey was anonymous, and the questions concerned the operators' opinions on the QRQC method. The use of a survey questionnaire as a research method allowed for a direct measurement of the examined characteristics and behaviors.

A representative research group was randomly selected from the operators, which constituted part of the employees who held the position of production operator. The study group consisted of 20 people. Due to the fact that a similar number of men and women worked on the line, it was decided to conduct a study with a 50%/50% structure – selecting 10 women and 10 men for the study.

Among the respondents, most of the people were aged 26–35 (a total of eight) – 40%, followed by people aged 36–45 (seven) – 35%. The third largest group in terms of size was people aged 18–25 (four) – 20%, and one person was from the 46–55 age group – accounting for 5%. The study did not include any representative of the 56–65 age group. The educational structure of the employees was almost uniform, as 19 people had secondary educations; this constituted 95% of all of the respondents (one person had only a primary education).

Analyzing the period of employment in the enterprise of the respondents, the largest groups were those with 1–2 years and 3–10 years of work experience; in both cases, there were seven people – constituting 35% of the entire survey group. The next positions were taken by four people with less than one year of work experience (a share that was equal to 20%), and two people had more than ten years of experience in the company in question (a share that was equal to 10%).

The randomly chosen and representative group of respondents includes a full cross-section of people of various ages and experiences. These people were trained in the QRQC methodology and participated in the QRQC process numerous times.

It can also be assumed that, due to their lack of higher education, the surveyed people did not have the opportunity to become familiar with quality assurance tools and methods during their school educations; their knowledge was acquired only during their training and work in the surveyed enterprise.

In the survey, a questionnaire was prepared that included 25 questions (20 of which were formulated in the form of theses), and a five-point Likert scale was used to evaluate them.

The Likert scale was described as follows:

1 I strongly disagree.
2 I tend to disagree.
3 I have no opinion.
4 I tend to agree.
5 I definitely agree.

To assess the reliability of the questionnaire for collecting the survey data, the Cronbach's alpha coefficient was used. This is one of the coefficients that is most often used in psychology. The reliability that was measured in this case concerned the internal consistency of the tool (survey questionnaire) and whether it did it well and presentably. The calculated Cronbach's alpha parameter for the survey was 0.77, which defined the test as "good". The higher the internal consistency of a test, the higher the Cronbach's alpha value. It is assumed that the minimum values of this statistic should be greater than 0.70.

6. DISCUSSION OF SURVEY RESULTS

The results of the answers to 20 questions are presented in the forms of box plots in Figure 2. Analyzing the median value of the answers to all of the questions was 4 (the mean was 3.5), which may suggest that the respondents generally tended to agree with the theses that were ut forward during the study. The median for the men and women was 4 (the mean for the men was 3.56, and for the women – 3.48).

After analyzing the results, it could be seen that the respondents were trained in the use of the QRQC method and that it was understandable to them (Questions Q14 and Q13). They approached their analyses with due care (Q20), and completing the QRQC was not a negative obligation for them (Q18)[1]. This was a good signal for the entire organization and proved the conscious use of the method among the operators on the production line.

The respondents pointed out the advantages of the QRQC method in most cases, agreeing with the following theses:

- QRQC makes it easier to solve encountered problems (Q6),
- QRQC form is easy to complete (Q7),
- form is correctly prepared and contains all necessary fields for analysis (Q21).

Most of the respondents indicated further advantages of the QRQC method, but some of them did not agree with these theses:

- QRQC method allows one to detect cause of problem (Q9),
- QRQC metod allows one to better and easier understand what is happening on production line (Q10),
- QRQC form is necessary document (Q11),
- QRQC form standardizes reporting of existing problems (Q19),
- QRQC metod allows one to increase awareness of product quality (Q23).

[1] Here, the thesis was that completing the QRQC was only a negative obligation for me.

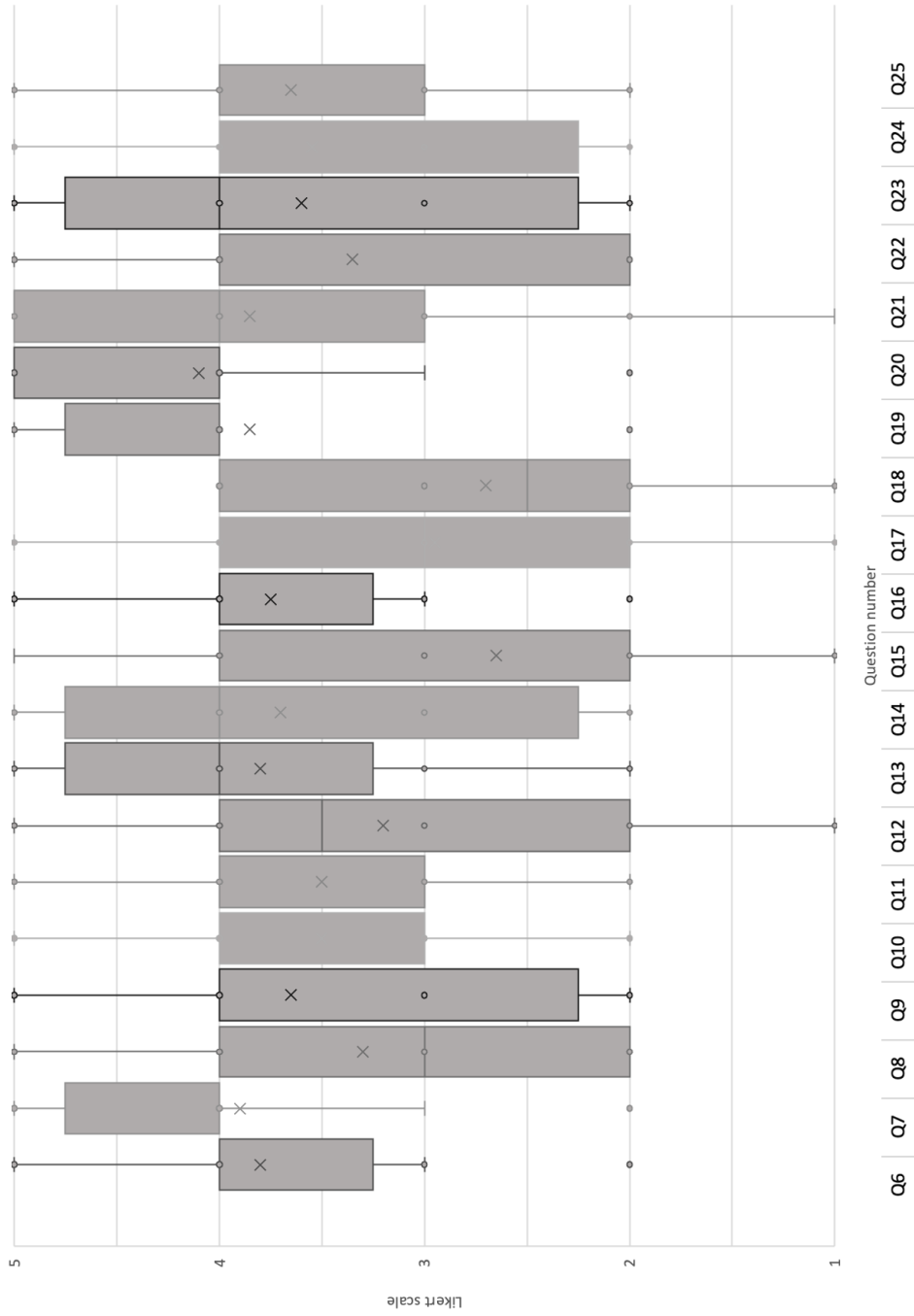

Fig. 2. *Boxplots for Q6–Q25 survey questions*

The majority of the respondents indicated that they had no opinion on the following statements:

- QRQC method allows for better communication between operator and leader (Q8),
- QRQC form does not require much time to complete (Q22).

The respondents indicated that the planned activities in QRQC are being implemented (Q24), although some had no opinion on this matter. Also, the effects of the implemented activities were positive (Q25), and the QRQC analyses were sources of knowledge for them regarding any possible problems that may be encountered in the future (Q16).

The respondents were quite critical of the leader's actions, and these questions received the lowest ratings. Pointing out that the leaders did not conscientiously check the QRQC analyses that were prepared by operators (Q17), they did not congratulate and celebrate reporting and conducting QRQC (Q15). Additionally, they indicated the lack of a task on the topic that QRQC allowed for better communication between the operator and the leader (Q8), which did not reflect well on the leaders' work.

Two control questions were formulated as part of the study. Their aim was to examine whether the surveyed people consciously answered the questions. These were worded as follows:

- QRQC form is a necessary document (Q6),
- QRQC form is unnecessary, and filling it out is tedious chore (Q13).

The answers to these theses were as follows: I rather agree (Q6), and I rather disagree (Q13); this can be interpreted as the operators consciously answering the questions.

The women were more critical – their answers contained the lowest and highest averages of the individual answers. The largest absolute differences between the average answers of the men and women could be seen in the following questions:

- Q24 (question answer value of 1.1) – the change in the work standard indicated in the form has been implemented (most women had no opinion here);
- Q20 (question answer value of 0.8) – I always fill out the form carefully (most women definitely agreed here).

7. CONCLUSIONS

The results of the research that was conducted on the evaluation and the use of the QRQC method allowed us to draw conclusions in several aspects, which were as follows:

1) The operators on the production line know and use the QRQC method in their company.
2) QRQC makes it easier for the operators to solve the problems that they encounter, and the QRQC form itself is prepared correctly.
3) The operators approach QRQC analyses with conscientiousness and care.

4) The vast majority of the operators see and confirm the basic advantages of the QRQC method.
5) The operators have indicated the positive effects of using QRQC in their enterprise.
6) The operators have evaluated the work of the leaders and their support negatively.

After analyzing the data from the survey, the authors of the article prepared the following recommendations based on their conclusions:

1) Employee skills should be continuously improved through training and involvement in QRQC analyses.
2) Management should constantly emphasize the importance of using the method and its positive effects (because the example comes from above).
3) Leaders should engage in the QRQC process.
4) After completing the QRQC procedure, the leaders should clearly communicate completions and acknowledge the contributions of their team.
5) Training should be organized for leaders in communication, providing feedback, motivating, and recognizing the needs of their employees – perhaps they are not aware of how their involvement and the feedback they give affect others.
6) A review of the scope of the leaders' responsibilities should be carried out – it is possible that the lack of an appropriate commitment is due to an excess of other responsibilities.
7) An idea to better motivate and support the activities of the leaders may be, for example, organizing a competition for the best leader of a zone where the voters would be the operators.

The study that is provided and described in this article is a case study that is specific to the given industry, location, and culture of the company. The results of the study may help the examined company make mature decisions regarding the application and improvement of the functioning of the QRQC method. The conclusions from the study can be used by other companies that use this method or want to use it in their problem-solving practices in an effective and efficient manner.

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Digital Photogrammetry and CAD/BIM Technology in Reconstruction of Computer Models for Concept of Virtual Factory

Olena Stryhunivska*

Abstract. This research article aims to check the feasibility of combining digital photogrammetry and CAD/BIM technology in an effort to develop a 3D digital model for the concept of Virtual Factory. The main objective of this research is the evaluation and continuous improvement of all of the relevant processes of creating spatial layout planning. During the research, a 3D floor plan of a laboratory was created to find matching common features for these methods. The article presents a comparative analysis of the time that is needed to create a spatial layout in which one can see exactly where each particular element is placed in the spatial arrangement of a point-to-point montage. On this ground, one of the key elements that determines the success of a design result is the effectiveness of the design process. Furthermore, the article indicates the scope of possibilities for using modern photogrammetric techniques for inventory building interiors and compare the speed of the measurement processing using PhotoModeler Scanner and ArchiCAD software.

Keywords: Virtual Factory (VF), facility planning, model VF, BIM technology, digital photogrammetry

Mathematics Subject Classification: 93B51

JEL Classification: O14

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1. INTRODUCTION

Dynamic changes in facility management incline us to make decisions about coherent and progressive development in accordance with its established objectives. The effectiveness of the measures depends on many factors, including creating a comprehensive vision, obtaining investment costs, and analyzing market forecasts. In addition, the

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main prerequisite for success is reducing the time that is required for implementating innovative solutions (e.g., the relocation of various machines or re-planning for the modernization and improvement of a factory). The consequence of decision-making is the need for a rationally located space with a functional and safe layout as well as the design of a plant and its technical equipment. However, the effectiveness of building-surface management largely depends on the selected methods of spatial layout planning. This publication covers the subject of using layout-plan modeling for the reconstruction of objects – particularly when searching for the best solution that helps develop virtual models quickly and efficiently. This article also offers an overview of the possible methods for 3D modeling and spatial-data transfer into ArchiCAD, thus enabling designers to collect and handle planning rules and design data with ease. The description of the methods focuses on taking measurements using laser scanning and digital SLRs as well as their advantages, disadvantages, and limitations according to a documented building. The next part of the article includes a spatial-data transfer into BIM (building information modeling) software (Stryhunivska, 2019).

2. DATA-ACQUISITION AND COMPARISON OF MEASUREMENT TECHNIQUES

In order to perform a reconstruction of a computer model, photos of parts of a laboratory were taken. The data was processed into a 3D model using PhotoModeler Scanner. The software provides the loading of photos from a camera as well as the production of accurate measurements, diagrams, and models from those photos. In addition, all of the appropriate measures of the parts of the laboratory were carried out analogously by means of a laser scanner in order to import data into the ArchiCAD software. The combination of measurement methods for 3D modeling is shown in Figure 1 – based on Stryhunivska (2015).

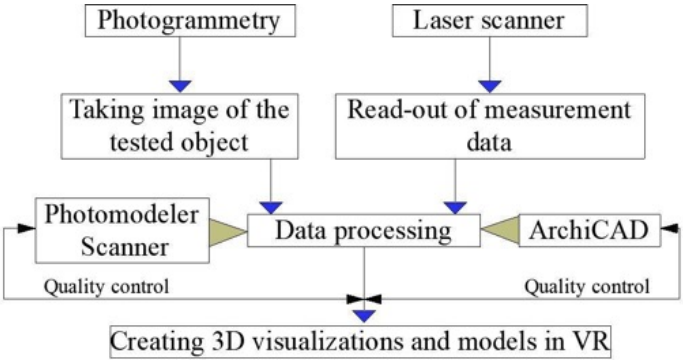

Fig. 1. *Combination of measurement methods for 3D modeling*

Data-flow management during layout creation allows for the exchange and systematization of information by using the same digital environment in which documents can be shared, verified, and updated. In this way, errors can be avoided during

the project, and savings can be made by checking all of the stages of a project in advance (Guzzetti et al., 2020). However, the main factor is to compare the measurement speed and the processing of the input data; this allows us to manage the spatial-planning time.

2.1. Factors that affect measurements

Research has been carried out to check the influence of various factors on the results of room measurements. The experiment took the fact that the following elements were measured into account: the arrangement of the walls, doors, windows, and objects inside the room. Considering the influence of various factors on the performance of the measurements is an important element in making decisions in order to achieve the effectiveness and accuracy of the measurements. At the same time, one question arises: how will all of the factors that affect the measurements be verified? Taking these factors into account, they can be divided into two groups:

1) factors that are influenced by person performing measurements,
2) factors that are not influenced by person performing measurements.

Going back to the first group, the following factors can be included:

- performing or not performing check measurements,
- providing details on how compliance is to be measured and verified,
- taking measurements alone or with another person.

The second group includes the following factors (Stryhunivska, 2015):

- experience of person using measuring equipment devices,
- light (part of day – evening/morning), as measuring device reacts to daylight and artificial light,
- microclimate (hot/cold) – measurements can be carried out at different temperatures,
- fatigue at work (start/end of working day) – fatigue leads to slower measurement processes,
- mechanical vibrations and noise – in industrial facilities during working of technological equipment devices, shocks, specific vibrations, or noise may occur in the room (which make it impossible to carry out measurements),
- gaseous and particulate pollutants – particulate pollutants (crushing, grinding, cutting) and condensation (i.e., solidification or condensation of metal vapors make accurate measurements impossible).

2.2. Planning experiment: choice of factors

Based on an analysis of all of the possible modifiable factors, three factor were selected that were deemed to have the greatest impact on measurement speed. From the first group, the following factors were identified: performing or not performing check measurements, and the method of measurement (camera or laser scanner). From the second group, the following factor was selected: light (part of a day – evening/morning).

According to the experiment, the number of iterations should be equal to 2^3 (2^3 = 8 factor – level combinations). An important stage of the analysis is the plan of the experiment that is being tested with accurate measurement results in minutes and the full data package. As a result, diagrams are produced; thanks to this, one can carry out an analysis according to the experiment (Figures 2–4).

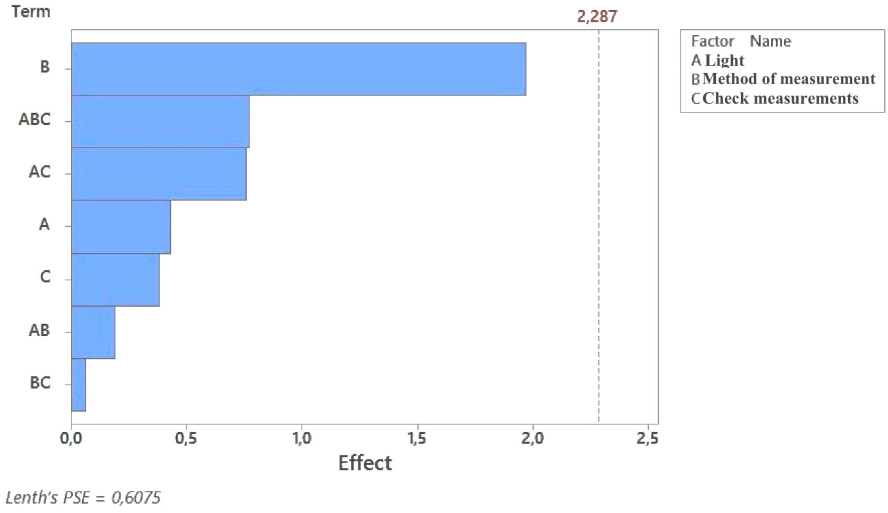

Fig. 2. *Pareto chart of effects: response in minutes;* $\alpha = 0.05$

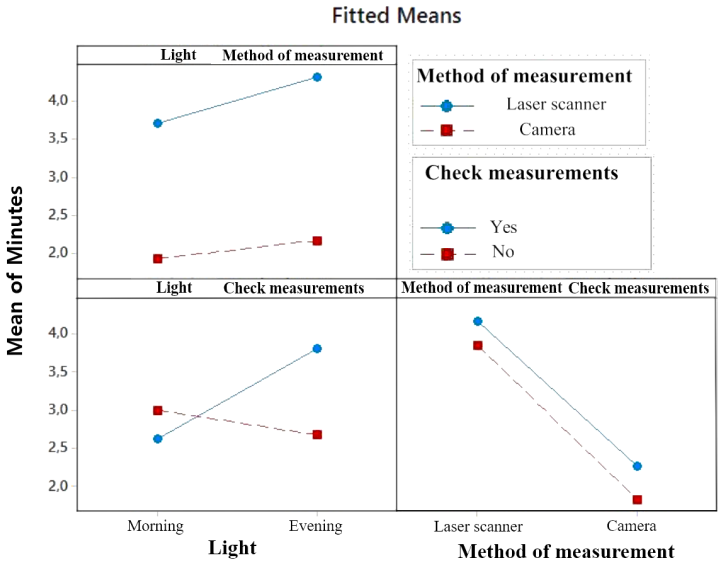

Fig. 3. *Interaction plot for minutes*

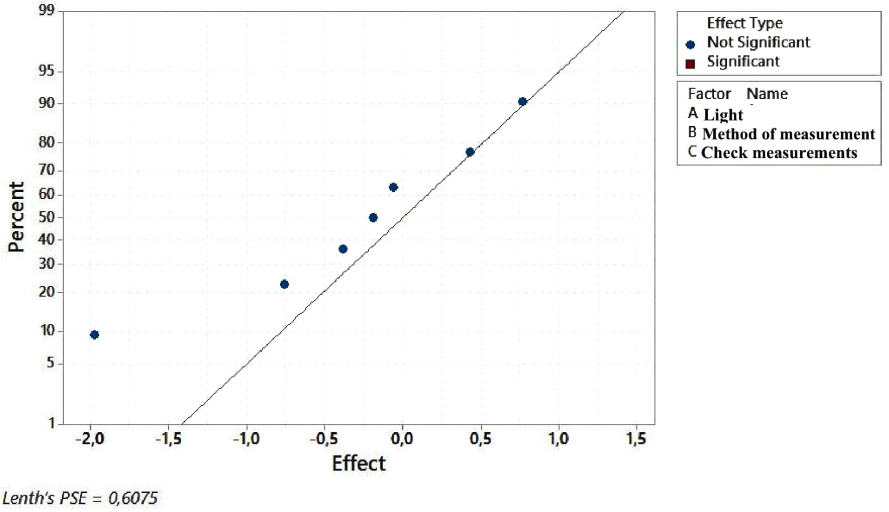

Fig. 4. *Normal plot of effects: response in minutes;* $\alpha = 0.05$

A Pareto chart that signifies the important factors was created. The chart displays which factor has the greatest impact on the results. The reference line for statistical significance depends on the significance level (denoted by α or alpha). As can be seen in Figure 2, Factor "B" (which is "method of measurement") is potentially important. Factor "C" ("check measurements") is another factor that needs to be considered. These factors are statistically significant at a 0.05 level with the current model terms. The Lenth's PSE (pseudo-standard error) indicator that is displayed in the chart is based on rare insignificant errors. In this experiment, Lenth's PSE was equal to 0.6075 (Figure 2).

The "interaction plot" chart (Figure 3) shows that an influential interaction can be observed between two factors: "method of measurement" and "check measurements" (however, this did not have a key impact on the results), while the remaining interactions were characterized by low levels of importance.

The next "normal plot of the effects" chart (Figure 4) demonstrates that the most important factor that affected the measurement speed was the "method of measurement" factor. The "Normal plot of the effects" chart displays the positive effects on the right-hand side of the chart and the negative ones on the left-hand side. The more a point is away from the normal plot, the more it affects the main effect. In the chart, the "method of measurement" factor is much further away from the chart line than the other factors; this ensures that the measurements using a laser or camera have the greatest impact on the results. Considering the outcomes, it was concluded that the "method of measurement" factor was distinguished and affected the measurement result.

The next "main effects" chart (Figure 5) presents the fact that the greatest angle to the y-axis of the chart characterizes the "method of measurement" factor. This is the most significant factor that confirms the conclusions that were drawn from the

previous charts. The other two factors ("light," and "check measurements") were of little importance; however, they can be meaningful in the interactions. The "main effects" chart shows that the "check measurements" factor had a greater effect on the results than the "light" factor did. Due to the "main effects" chart, it can be emphasized that the best combination of factors that guaranteed an impact on the speed of the measurements was the combination with a camera without a check measurement. All of the charts displayed the greatest impact of the "method of measurement" factor on the measurement efficiency. The shortest time for obtaining the measurement data had a measurement factor using a camera in the morning without a check measurement. Comparing the charts with the outcomes of the experiment, it can be concluded that the result of the factor that obtained the fastest data was 1.57 minutes (Table 1). Based on knowledge and experience, it can be observed that cameras take worse photos in the evening. Furthermore, it can be assumed that the "method of measurement" and "light" factors are very dependent on each other; from this data set, however, it can be acknowledged that they did not make that a relationship.

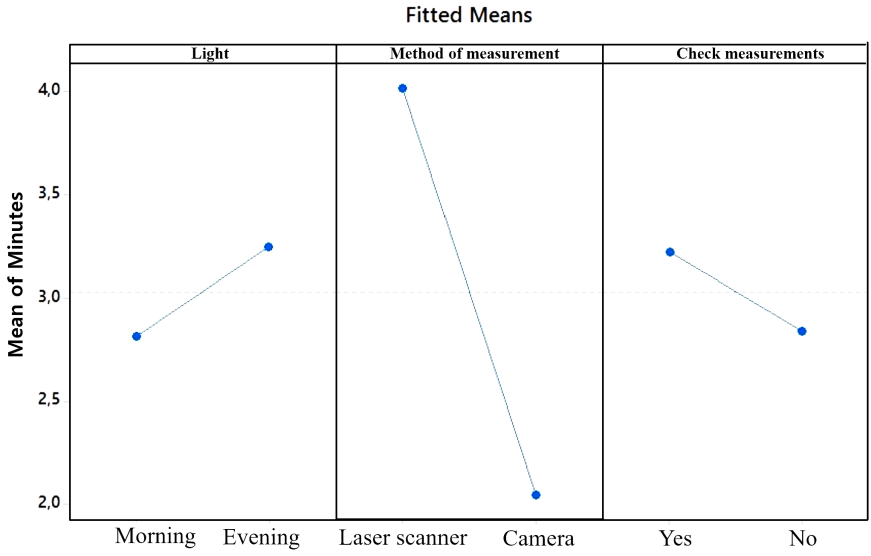

Fig. 5. *Main effects plot for minutes*

In the cases of advanced experiments with large numbers of factors on many factor-level combinations, those effects that affect measurements can be distinguished. The "method of measurement" factor (the measurements that were taken using the camera or laser scanner) contains information on the speed of measurement. The advantage of this is a feasibility to create 3D models directly on-site after taking measurements with a laser. Photos can be taken faster with a camera (1.57 minutes) — in this research, a Canon EOS 100D camera was used; however, the editing required more time (Table 1). The point is to download photos to a computer and edit them with the assistance of the PhotoModeler Scanner software.

Table 1. *Advantages and disadvantages of group decision-making: analysis of results that affect creation of 3D models*

Light	**Method of measurement**	**Check measurements**	**Measurement results [min]**	**Measurement time [min]**	**Time of creation of 3D models – Photo-Modeler Scanner [min]**	**Time of creation of 3D models 3D – ArchiCAD [min]**
Evening	Laser scanner	Yes	23.55	23.6	–	143.6
Evening	Laser scanner	No	11.47	11.5	–	131.5
Morning	Laser scanner	No	9.3	9.3	–	129.3
Evening	Camera	Yes	4.41	37.9	44.4	–
Morning	Laser scanner	Yes	18.32	18.3	–	138.3
Morning	Camera	Yes	3.11	36.6	43.1	–
Evening	Camera	No	2.38	35.9	42.4	–
Morning	Camera	No	1.57	35.1	41.6	–
Average time for camera				36.4	42.9	–
Average time for laser scanner				15.68	–	135.7

Importing photos to PhotoModeler Scanner takes about one minute. The next stage includes determining the dimensions of a room of a part of a laboratory and determining the control dimension (this takes about 1.25 minutes) in order to scale the object. It can be observed that obtaining measurements using a laser equals the time that is required to measure a room. The average time to obtain measurements using a laser is 15.7 minutes. However, the average time to obtain measurements using a camera is 36.4 minutes after taking the editing of the photographs into account. The average time to create 3D models with PhotoModeler Scanner is 42.9 minutes, whereas the average time for creating 3D models with ArchiCAD is 135.7 minutes. It should be taken into account that the time for obtaining laser measurements is 2.3-times shorter than the time for obtaining camera measurements. Furthermore, the time for creating 3D models with PhotoModeler Scanner is 3.2-times shorter than the time for creating 3D models with ArchiCAD. It is also noteworthy that the advantage of photogrammetric measurements is the rapid acquisition of real information in the form of photos (from which any information that is required at a later time can be received) (Stryhunivska, 2015).

3. CREATING VIRTUAL MODEL

Creating a virtual model requires solid knowledge from the participating designers; therefore, using a tool as powerful as BIM may be too difficult for most. It can be noticed that Graphisoft's ArchiCAD first implemented BIM under the virtual building concept (Sacks, 2013). Consequently, the transition to BIM does not require considerable effort for those designers who use ArchiCAD, as BIM implementation has been included. On the other hand, designers who have experience in designing are able to obtain the best performance from using BIM. To resolve the important barriers that are related to integrated work in design, the required competencies to use BIM should be clearly specified (Siebelink et al., 2021).

The exchange of models and input data between different software platforms is important for integrated and collaborative project teams. Designers are currently exchanging models with 3D-drawing packages and then exchanging models with computer design (CAD) applications (Pezeshki & Ivari, 2016). In a BIM design process, there are items of information that are assigned to the building elements in a BIM model that make up the whole project (2D or 3D geometric) and there are interactions among the elements (Dall'O' et al., 2020). In fact, all of the information that characterizes an object or a certain material is associated to the following (Daniotti et al., 2020):

- geometrical characteristics,
- performance of functional characteristics,
- typological characteristics,
- procedural characteristics,
- descriptive characteristics.

The second approach is based on loading a point cloud directly into the BIM software. This software supports the majority of basic point cloud data formats, and

point clouds can be imported into the software; then, it can create a 3D model in the desired format using BIM software instruments. This approach can be effectively used to solve the problem of data transfer, and the level of detail in model-creation can be selected directly according to the needs of the BIM designer. The original point cloud is still easily available to a designer for editing (Faltýnová et al., 2016). With the PhotoModeler Scanner software, the scanning process produces a dense point cloud (dense surface modeling – DSM) from photographs. Based on photos of virtually any sizes, it can produce a scale-independent object modeling.

Data processing to create a computer model was carried out using ArchiCAD and PhotoModeler Scanner. The model-creation structure had an impact on the final result. The advantage of ArchiCAD is the possibility of making the model easier to design. The 3D computer model can be used to give dimensions to 3D elements, the repetitive calculations of objects, and shape properties due to the intelligence that is contained in the model (Dadi et al., 2014). In addition, it provides the possibility to create both external and internal layouts. In contrast, PhotoModeler Scanner only allows for applying a texture on the walls, but the thickness of a window cannot be verified (for example). Consequently, there is a fundamental difference between these models; however, the dimensions of parts of the laboratory are the same. Due to the further analysis of the model in PhotoModeler Scanner (Figure 6), it could be observed that, after creating the model, the next step was to apply the texture of the photo.

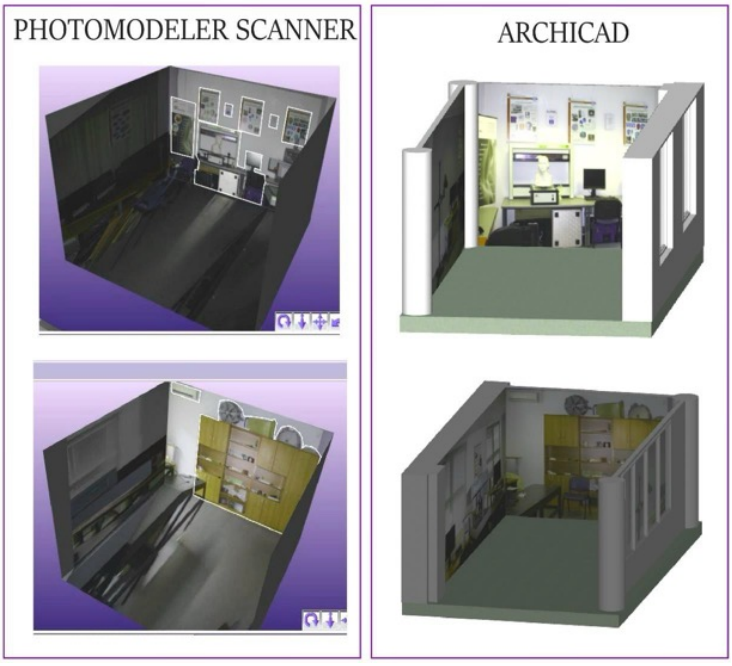

Fig. 6. *Comparisons of 3D visualization models – based on Stryhunivska (2015)*

Therefore, the quality of the model is affected by the texture (in this case, they were photos). If a photo was taken in the evening, the texture on the surface of the room looked dark; this affected the quality of the visualization.

If the speed of the model creation and the reproduction of all of the elements that are in a room are considered, PhotoModeler Scanner dominates in this case. In this study, it was necessary to divide the room into two parts and create two models of the right- and left-hand sides of the room in order to create a whole room model, as the camera was unable to take a picture of the whole area. However, this method did not significantly affect the speed of the model creation when compared to ArchiCAD. After analyzing the final models, it can be concluded that the model's appearance, visualization quality, speed, and accuracy differed significantly (Figure 7).

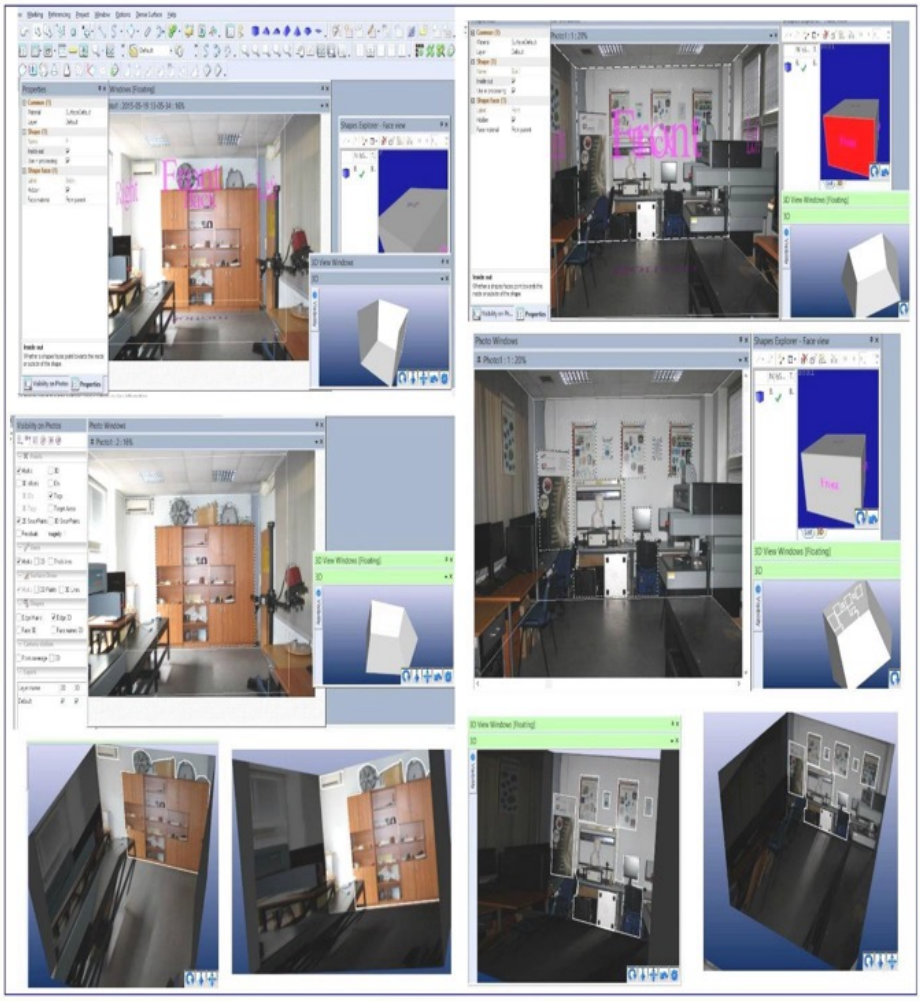

Fig. 7. *Comparisons of 3D visualization models – based on Stryhunivska (2015)*

Last, ArchiCAD software was used for real-time rendering in order to create a virtual reality. It should be emphasized that a visualization between users and objects in virtual reality certainly takes place using interaction metaphor techniques. Each 3D object that is stored in a room has its own characteristics (size, shape, color, etc.) (Nugraha Bahar et al., 2014).

The advantages and disadvantages of the discussed software are indicated. The key goal is to determine the effective measurement method for converting measurement data into a digital 3D model. A detailed a summary of the pros and cons can be seen in Table 2.

Table 2. *Advantages and disadvantages of group decision-making*

ArchiCAD		**Photomodeler Scanner**	
Advantages	Disadvantages	Advantages	Disadvantages
Detailed 3D model, Standard Parts Library 3D,	Measurement time is longer than when taking photos	Measurement time using camera is shorter	Lack of 3D-parts inside
Creating 2D and 3D model at same time	More time to create 2D model	Exact 3D model using texture	Long rooms require taking many photos and composing them
Software generates high-quality CAD 2D and 3D models	3D element library limited	Photorealistic concept of project	Visualization quality depends on photo quality
Creating internal and external visualization of room at same time	More time to master basic scope of knowledge of software	Less time to master basic scope of knowledge of software	Internal or external visualizations of room depend on appropriate photos
CAD 2D and 3D models are used to compile technical files	Expensive software	Cheaper software	Photos are basis for visualization, not for compilation of technical files
It is easy to change layout of room	3D graphics card and more RAM are required	Graphics card with good 2D rendering capabilities is recommended	New photos are needed to change layout of room

Depending on the design method that is chosen, the exchange of information affects the quality of the communication, product quality, and delivery time. BIM defines building-information modeling, not an object. Information modeling involves creating a virtual representation of a room. The BIM model consists of intelligent objects and verifies their locations. In particular, the assigned parameters specify their geometry, locations in space, relationships with other objects, and other specific features (Ustinovichius et al., 2018).

4. DISCUSSION

The research article highlights the merging of digital photogrammetry and CAD/BIM technology to construct a 3D digital model for the concept of a virtual factory, with a primary focus on evaluating and enhancing those processes that are related to spatial-layout planning. The study's key objective was to assess and refine the efficiency of spatial-layout planning through the integration of these technologies. One of the pivotal aspects of the research involved generating a 3D floor plan of a laboratory in order to identify commonalities between the digital photogrammetry and CAD/BIM technology. Through a comparative analysis, the study examined the time that was required for creating spatial layouts, underscoring the significance of efficiency in the design process. Additionally, the article explored the potential of contemporary photogrammetric techniques for inventorying building interiors and compared the processing speed of the measurements that used PhotoModeler Scanner and ArchiCAD software. The findings of the research underscored the substantial influence of the design process's effectiveness on the overall success of the design outcome. Moreover, the study identified various factors (including measurement methods and environmental conditions) that affected the speed and accuracy of the measurements. Notably, factors such as performing check measurements and choosing between camera and laser-scanner methods were recognized as significantly impacting measurement speed. Furthermore, the study discussed the strengths and weaknesses of different software tools like ArchiCAD and PhotoModeler Scanner for constructing 3D models, highlighting the pivotal role of BIM technology in generating virtual representations of rooms that encompass intelligent objects and parameters. The study contributes significantly to understanding how different measurement methods influence the efficiency and performance of spatial layout design. Through empirical experiments and result analysis, the research provides valuable insights into optimizing the design process for creating 3D models within the framework of the Virtual Factory concept.

Further research developments hold significant potential. There are plans to integrate these design methods with Archicad AI Visualizer, which augments details, context, and ideas to an original concept by generating design alternatives during the early design phase. This integration is poised to revolutionize the early design phase by leveraging the capabilities of AI in order to generate an array of refined design variations seamlessly and efficiently. By utilizing text prompts, Visualizer can produce a diverse range of design alternatives without necessitating the manual creation of multiple intricate models. The envisioned combination of design methods with Archicad AI Visualizer holds substantial potential for enhancing design exploration and decision-making in the Virtual Factory context. This planned integration signifies a continued effort toward enhancing the capabilities and applicability of these technologies in advancing spatial-layout planning and design processes.

5. CONCLUSION

Combining measurement methods in order to obtain a high-quality 3D model is increasingly being used. Laser-scanning and photogrammetric methods have been used and tested for designing parts of laboratories. The tests showed that both methods

could be used when creating a layout (Stryhunivska, 2019). The use of a specific method is based on taking the project requirements and the speed of its implementation into account. This paper's primary contribution to the body of knowledge is identifying how different measurement methods influence the performance of created layouts. By conducting a cognitive task experiment, the performance and speed of creating a 3D.

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Decision Making in Manufacturing and Services
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Product in Dentistry Services: Benefits Obtained by Consumer/Patient from Dental Service

Kajetan Suchecki*

Abstract. Health care is a specific branch of the economy in which the principles of the free market clash with the activities of the state; however, dentistry is a part of health care in which commercial activity clearly dominates (albeit significantly regulated by legal regulations). Therefore, the competition between entities that provide dental services is significant and is relatively rarely based on the price of medical services but rather emphasizes the benefits that the patient receives by choosing a specific provider. The purpose of this study's research was to identify the benefits and values that dental service consumers obtain based on the product that they receive. The work is based on the case study method and personal observation as part of the implementation of professional duties in 2022–2023. The purpose of dental services is to present them as an extensive product with a wide range of benefits and values that are offered to the consumer. The work also aims to give those entities that operate in this market the opportunity to use good practices and adapt them to their activities.

Keywords: product, benefits, economics of health care, marketing in dentistry, consumer in dentistry

JEL Classification: L84

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1. INTRODUCTION

Health care is a specific branch of the Polish national economy. Until recently, it was excluded from the economy. After changing the model of the health care system to one that was largely an insurance model in the 1990s, it became the current industry health care that was followed by the marketization of this activity and the treatment of the patient – not only as a medical case, but also as a consumer (Przybyłka, 2011).

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Researchers who discuss the topic of health care from the economic or managerial sides particularly focus on the description of the health care market as a whole, the functioning of the system, or its financing (Golinowska, 2013; Golinowska & Tambor, 2014; Kantyka, 1998; Markowska & Węglińska, 2019; Nojszewska, 2011). Consumers of these services are relatively rarely the focus of researchers' attention (Janoś-Kresło, 2007), and this topic has been discussed more often by scientists from countries other than Poland; e.g., Metcalfe et al. (2018). In Poland, research has been carried out on the factors that determine consumer behavior in the health care market as well as the impact of marketing activities on triggering specific behaviors, among other topics.

Marketing activities in the health care market can be met with misunderstanding or even resistance (Rudawska, 2004). This may result from the legal provisions that limit the possibilities of promoting medical services in Poland (in particular, the ban on advertising these types of products or the restrictions on physicians appearing in advertisements) (Barańska, 2019). However, this approach may result from a misunderstanding of marketing as such. Marketing is a set of diverse tools that is meant to influence the consumer in order to induce specific behaviors, such as the purchase of goods or services (Przedworska, 2023).

One of the elements that researchers usually mention first in many concepts (such as 4P, 5P, and 7P) is the product (Goi, 2009). It is not simply a good or service that is offered by the seller but is, in fact, a more-or-less extensive set of values that the consumer can receive (Pabian, 2020). Various elements of the product (both material and purely service/simply informational) contribute to a more-complete fulfillment of the consumer's needs (Krawiec & Szymańska, 2017); as a consequence, this can lead to the creation of a competitive advantage over other entities in the same market and help a company achieve its objectives (Wójcik et al., 2018).

The most common product on the health care market is a medical service. This usually consists of elements such as medical examinations and advice, opinions on health, the treatment itself, or various technical activities (for example, those that are related to the preparation of prostheses or orthodontic appliances) (Bukowska-Piestrzyńska, 2011). Particularly notable are the so-called hard components of the service process; i.e., the necessary equipment and supplies of medical equipment and devices, the qualifications and skills of the basic and auxiliary staffs, or the time that is involved in waiting for both the service and the actual implementation process (Krot, 2018).

Under the conditions of a market economy in which business entities must compete with each other, the choice of a product from those that are offered on the market is very rarely only related to meeting the basic need that is the core of the product. The offer must stand out and satisfy any other needs that are related to the main one (in the forms of the elements of a real or extended product). This consumer evaluates the options that are available to him/her and, thanks to the information that is collected, decides to choose the option that will meet his/her needs as fully as possible under the existing conditions (Szcześniak, 2020). Each consumer may value the individual elements of the structure of an offered product differently; in the cases of the adequately identified needs of the market segment that have been selected by the business entity, however, consumer values may be an important competitive

factor (Szymańska, 2022). Consumer value is strongly related to subjective utility. This usefulness can be considered at four levels: form (the material dimension of the offered product); time (waiting for the product, the duration of the service, etc.); place (e.g., in connection with the possibility of reaching the place of business); and ownership (the possibility of also using the product outside the location of the manufacturer/service provider) (Knop-Iwińska & Szymańska, 2015; Smoleń, 2013).

It can be said that a research problem arises as to which benefits and values that consumers of dental services obtain when purchasing a product (dental service); the research goal of this work was to identify these benefits and values. It was hypothesized that it is possible to define the benefits that are obtained by the consumer when providing a dental service that is identified within the different levels of the product structure as understood in a marketing manner.

2. RESEARCH METHODOLOGY

In particular, the case study method was used in this work. This method employs "a detailed description, usually of a real economic phenomenon (e.g., an organization, the management process, its elements, or the organization's environment) in order to formulate conclusions about the causes and results of its course" (Grzegorczyk, 2015). This allows us to present socioeconomic problems. For a more-complete picture of the phenomenon that is being analyzed, it is recommended that subsequent research be carried out using other methods (preferably using a triangulation of research methods) (Pizło, 2009). Researchers recommend using the case study method "when the boundaries between the phenomenon under study and its context are not clearly defined and may have a significant impact on a given phenomenon, as well as, in the study of complex phenomena that involve many variables and elements where not just one outcome is expected or in research that is based on many different sources of evidence" (Kożuch & Marzec, 2014). In the case study method, the purpose of the study may be explorative, descriptive, or explanative (Yin, 2003).

This work uses a description of a dental service from a marketing perspective. Participant observations were also used as a supplement due to the author's professional activity in the dental facility. This observation was made during the period of September 2022 through April 2023, when the researcher worked as the manager of this entity. This entity operated in the Śląskie Voivodeship (in Bieruń-Lędziny County) in the form of a company according to the civil code. During the period under review, eight dentists and auxiliary staff were employed. The unit provided general dental services (particularly in the fields of conservative dentistry, endodontics [root canal treatment], dental surgery, pediatric dentistry, periodontology, prosthetics, orthodontics, and dental prophylaxis) as well as imaging diagnostics (X-ray and computed tomography). Due to the great diversity of the scope of the services in today's dentistry, it was decided that, in the case of a case study, it should not be a specific dental service but rather a dental service that is understood as generally as possible (thus representing the widest possible spectrum of medical services in the field of dentistry). This was mainly because many dental facilities (including the facility on which this case study

was based) treat dental service comprehensively. We can therefore talk about a specific system product that consists of individual medical services from various branches of dentistry. The analyses used the basic method of empirical science, i.e. induction, while realizing its imperfections which are also pointed out by researchers who are active in the field of social sciences (Ćwiklicki, 2010; Lisiński, 2016), and, as a supplement, the method of deductive reasoning. This approach provides an appropriate basis for future quantitative and/or qualitative research (Czakon, 2006).

3. BENEFITS OF DENTAL SERVICES – CASE STUDY RESULTS

Regardless of its nature, the structure of a product consists of several basic elements – researchers usually recommend three to five such elements. This is the core of the product; that is, the basic utility of the goods, the real product (i.e., what directly affects the perception of the good), and the extended product (the additional benefits that are offered when purchasing the goods) (Fazan, 2016). The authors of these papers have also pointed to potential products; i.e., certain theoretical innovations that may be initiated in the future but have not yet occurred. In the place of an actual product, Ph. Kotler and K. Keller (2016) proposed two separate levels: an expected product, and a generic product. In the case study that is being discussed, it was decided to refer to a three-element structure; i.e., the core product, the actual product, and the extended product.

In the examined case, the product is a service: "a specific type of activity that consists of the provision of work, which does not result in the creation of a new product" (Czubała et al., 2006; Lotko, 2017). The three-stage structure of a dental service as a product in the marketing sense is presented in Table 1, along with the values and benefits for the patient.

Table 1. *Product structure – dental service as related to benefits and value for consumer*

Entity	**Benefits and value for consumer**
Core of product	
Providing dental services	Improving or maintaining health (understood as physical, mental, and social well-being)
Real product	
Course of consultation and dental procedure	Comfort during procedure, calmness, sense of confidence
Effect of dental treatment	Patient's sense of self-confidence after treatment
Improving patient's quality of life	
Time for providing health services	Feeling of being taken care of
Waiting time for health services after registration	

Table 1 cont.

Comfortable and convenient days and hours for patient	No immediate health problems after treatment
Punctuality	Saving time, feeling of professional service
Maintaining medical records	Feeling confident in treatment process
Information regarding diagnosis, diseases, proposed treatment process, and risks	
Information about course of treatment	
Information about provided medical services (e.g., on website of dental office)	Sense of decision-making and influence
Possibility of choosing offer	
Digital diagnostics and visualization of expected end result	Striving for intended final effect of treatment
Medical recommendations after procedure	
Medicine prescribed by dentist	
Prevention and hygiene packages after treatment	Awareness of need to maintain effect of dental treatment
Maintaining effect of dental treatment	
Information regarding costs for providing medical services	Sense of financial security
Education, skills, and experience of dentist	
Education, competencies, and experience of support staff	
Medical devices that constitute basic equipment of dental office	
Medical devices that constitute specialized equipment for dental office	
Disinfection and sterilization devices	
Auxiliary equipment for dental office	
Dental materials	
Certificates that confirm quality of provided dental services in office	Sense of medical security
Sense of treatment effectiveness	
Sense of health security (understood as belief that health care services will be properly provided)	
Medicine administered during visit	Sense of security
No pain	
Possibility of contact with dental office staff (personal, telephone, SMS, e-mail, Facebook Messenger, and others)	Time-saving, convenience, and contact that is customized to needs and characters of clients/patients (e.g., introverts)

Table 1 cont.

Entity	**Benefits and value for consumer**
Extended product	
Readiness for emergency admissions (so-called ”pain patients”)	Certainty of access to dental services
Repair and maintenance of manufactured dental prostheses	Quality assurance
Instruction on preventive measures in field of oral hygiene	Expanding their competencies
Reducing risk of other oral diseases	
Easy access to medical records for patient	Certainty of access to one’s own medical records
Warranty for provided dental services	
Warranty for provided dental services (including their scopes, durations, and conditions)	
Speed and quality of complaint-handling process	Certainty of quality of dental services
Possibility to choose various forms of payment for dental services	Convenience of payment
Possibility of financing payments for dental services	Increasing financial availability
Customer service (in particular, empathy and professionalism of employees)	Comfort of using service (including at stage before treatment)
Reminders of upcoming visits	
‘ Information about visit after registration	Comfort
Increasing certainty of providing dental service	
Complementary goods for prevention and oral hygiene	
Possibility to remotely order preventive and oral-hygiene products and deliver them to patient’s place of residence or collection point	
Complementary medical services	
Access to aesthetic medicine services (e.g., whitening)	Product package
Comfort and time-saving	
Feeling fully taken care of	

Like any medical service, the core of a dental service product is the performance of a specific action that is aimed at preserving or restoring health; this health effect is considered to be the primary benefit that a patient/consumer receives. It should be noted that health is broadly defined as one's physical, mental, and social well-being.

As part of a real product, such elements of a dental service have been identified as:

- the course of the medical activities,
- the effect of the treatment,
- the waiting time for the service (from the moment of registration),
- the time for providing the health services (which should be neither too short for the expected medical effect nor too long and tiring for the patient),
- the punctuality of the visit,
- keeping medical records (including in electronic form),
- all information regarding treatment (the diagnosis, course, and visualization of the expected effect), post-treatment recommendations, and prescription drugs as well as the qualifications, knowledge, and experience of the staff (medical [dentists, hygienists, and hygienists] and auxiliary [dental assistants, registration staff, managers]),
- all of the medical and auxiliary devices and office equipment,
- the medications that are administered during the visit (most often anesthesia),
- the various possibilities of contact with the healthcare provider.

Within these product elements, the following values and benefits for a patient/consumer were identified in particular: comfort, sense of self-confidence and certainty of medical quality, peace of mind, sense of being taken care of, quick relief from health problems, sense of agency and co-decision-making, ability to choose according to one's capabilities (also financial), a sense of the need to strive for the final effect of the treatment, a sense of financial security ("can I afford this?"), medical security, epidemic security, a lack of pain, time savings, and a form of contact that is tailored to the client's needs and preferences.

The extended product is identified as the readiness to accept patients who report toothaches, the repairs and maintenance of dental prostheses, educational activities in the field of oral hygiene, easy access to the patient's own medical records, warranties/guarantees for dental services and the complaint process, the possibility of choosing various forms of payment, the possibility of crediting services, patient service (help, empathy, and solving problems and disputes), reminders and information about visits, complementary products (both dental goods and other services), the possibility of the remote ordering of oral hygiene products, and other sales. As part of these activities and product elements, the following benefits and values that are received by the patient/consumer have been identified: the certainty of access to dental services, the certainty of the quality, the extension of one's competencies in maintaining the effects of a dental treatment, minimizing the risk of complications or further diseases, the certainty of access to medical records, increasing financial access to dental treatments, the convenience of payment, comfort and minimizing the stress that is associated with remembering appointments, product packaging, and time-saving.

4. DISCUSSION

Identifying a product's structure elements is, to some extent, subjective and may be different for specific dental services (such as tooth extraction, orthodontics, or prosthetic treatments). However, an attempt was made in this study to approach this topic as comprehensively as possible, as the product was comprehensive dental treatment (not a single specific service).

Within the identified product elements, one can find those that can be classified as activities within the other "P"s of the marketing mix. However, it was decided to treat the product more broadly due to the wide range of values (i.e., in reference to the 4C concept) that the patient/consumer requires and can receive. Of course, price is also such a value and is often a decisive factor when choosing a service provider; however, other values have also been indicated (especially when considering the price differentiation of dental services and the still-insufficient supply in this area) (Rzeźnicki et al., 2018).

It should be remembered that the issues of value and benefits for a client (who is a patient in this case) are also subjective and will result from the preferences and individual needs of each individual, among other things (Majchrzak-Lepczyk, 2019). As indicated in the literature on the subject, "customer value is the surplus of benefits that is subjectively perceived by a customer over the subjectively perceived costs that are associated with the purchase and use of a given product" (Szymura-Tyc, 2005).

Sitarz and Tymczyna-Borowicz (2020) stated that the COVID-19 pandemic may have been one of the factors that increased public health awareness and that patients may increasingly pay attention to those product elements (dental services) that are not directly related to the treatment itself but may affect their well-being or simply their comfort of life. Therefore, the client/patient view of the service will become more and more comprehensive (Arszułowicz, 2020), and good treatment performance may not be enough. Value management for the customer/patient may be a response to the emergence of those factors that determine the choice of an offer.

5. CONCLUSIONS AND RESEARCH LIMITATIONS

Identifying product elements (especially in the cases of service activities) are opportunities to meet consumer expectations. Basically, it does not matter whether a specific element is classified as a real or extended product from a company's point of view – especially in the case of service activities, where the manufacturer is also the seller quite often. However, the most important thing is to identify as many of the elements themselves as possible. This gives the opportunity to first distinguish those elements that are priorities for the company and its customers and then take action to improve them and better match them to the needs that are reported by their consumers.

This is particularly important for enterprises that operate in the healthcare market (including its submarket – the dental services market). Managers and owners of dental healthcare entities do not always realize that the product that they sell offers

patients not only emergency or preventive treatments but also a wide range of benefits that meet the needs of patients/consumers at various levels of the pyramid of needs. Although many offices cannot complain about a lack of patients (i.e., clients) – especially after the COVID-19 pandemic when the oral health of Poles deteriorated according to researchers, e.g., Wójcik et al. (2023), it is necessary to take a long-term view of this issue. Dentistry is the most commercial branch of health care; hence, the increased competition in this market. Competing for price can result in declines in the quality of dental services themselves, which will be unacceptable for many entrepreneurs; therefore, it is worth identifying as many elements of the product as possible that can be developed and, thus, acquiring loyal customers/patients.

Managers of dental entities should identify the benefits that their clients/patients expect and, thanks to the proper preparation of the structure of the products that they offer, meet their needs to the highest possible extent. The case study that is presented in this article may be helpful for them in running their businesses and making management decisions.

This work shows the product of the dental services market from a perspective that researchers have not explored so far. From an economic and managerial point of view, it is a market that is most often ignored by scientists despite its high nominal value; hence, it can be said that the existing research gap is filled somewhat.

Of course, case study research has many imperfections; it refers to a certain section of reality. Those entities that operate on the dental services market have different ownership structures, sizes, and service offerings, and they operate in different regions of the country. For some entities, those elements that are presented as parts of a real or extended product may take on the nature of a potential product. On the contrary, those elements that we could try to present as potential products in this case will already be part of the offers that are provided to patients for other more-innovative entities. To better illustrate the products that are offered, it is worth using qualitative research methods in any subsequent research on this topic – especially individual in-depth interviews (IDI) among the managers and owners of dental entities – as well as quantitative research among consumers to identify their preferences, needs, and purchasing behaviors; this will enable the managers and owners to better address the values and benefits that their clients expect from their service providers.

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Analysis of Municipal Waste Management in Municipality of Krakow

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Abstract. Rational waste management is an essential element in the process of transitioning the linear economy into a circular model. Those actions that are taken to achieve better results in this area are important for regional and local development as well as for the implementation of sustainable development goals. This article presents the requirements and rules for the functioning of waste management in Poland. Taking the structure of the system into account, the functioning of waste management in the municipality of Krakow was analyzed. Particular attention was paid to the problem of municipal waste segregation by the inhabitants of Krakow. As part of our own research, surveys were conducted among the employees of the Municipal Cleaning Company LLC (Miejskie Przedsiębiorstwo Oczyszczania w Krakowie – MPO Sp. z o.o.), which showed the scale of the deficiencies. The results of the research were helpful in proposing actions to increase the effectiveness of the waste-segregation system in Krakow.

Keywords: waste management, circular economy, sustainable development

JEL Classification: Q01

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1. INTRODUCTION

When people consume products, they generate waste; a significant part of this is packaging waste that is generated by eating food and using cleaning products and cosmetics (Guinness & Walpole, 2015). Until the late 1980s and early 1990s, food products in Poland were usually packaged in glass or paper. Glass packaging was intended for liquid and semi-liquid products. Glass bottles were returnable and deposits were imposed on them, which effectively reduced the amounts of waste and lowered packaging production costs (Borkowicz, 2022; Królczyk et al., 2015).

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Currently, the deposit-refund system is only used for some bottled beers. Paper packaging is also commonly used, in which loose products, meat, and dairy products are packed. Currently, products are most often packed in packaging made of plastic due to their widespread availability and low price. This leads to a large amount of plastic waste (Ajwani-Ramchandani et al., 2021; Minelgaitė & Liobikienė, 2019; Sadowski et al., 2021). Economic development caused the migrations of people to large cities and the rapid development of housing (single and multi-family) in them, which has affected the expansion of urban agglomerations. High population density makes municipal waste a serious problem, and waste management is one of the key challenges for local authorities (Jakubiak & Śliwka, 2013; Knickmeyer, 2020; Shah et al., 2021). European Union and national regulations impose the obligation to subordinate waste management to the principles of sustainable development on local governments. As part of the common policy of the European Union regarding waste management, a "waste-management hierarchy" has been established. Its stages are waste prevention, reuse, recycling (including composting), disposal (e.g., waste incineration with energy recovery), and finally landfill disposal (*Zarządzanie odpadami...* 2023; Pires and Martinho 2019). Polish regulations on waste management are adapted to EU requirements. *Ustawa z dn. 14 grudnia 2012 r. o odpadach* [the Act of December 14, 2012, on waste] (2012) stipulates that municipal waste is "waste generated in households, excluding end-of-life vehicles, as well as waste that does not contain hazardous waste from other waste producers, which due to its nature or composition are similar to household waste". According to the data from Główny Urząd Statystyczny (Statistics Poland) for 2021, the amount of waste that was collected in households in Poland was about 310 kg per capita. On the other hand, this was about 309 kg/person in the Małopolskie Voivodeship. In Krakow (the largest city in Małopolskie Voivodeship), 443 kg of this waste was collected per person (Bank Danych Lokalnych GUS, 2023). In large cities, the amount of waste that is produced per inhabitant is systematically increasing along with the increase in the standard of living of the residents. This is a major challenge for waste-management planners (Kalisiak-Mędelska, 2017; *Ustawa...*, 2012).

The purpose of this article is to identify problems that are related to waste collection in the municipality of Krakow and to find solutions that would improve the waste-management system in the municipality. Therefore, it was first necessary to assess the effectiveness of waste segregation by waste producers from the point of view of the employees of the waste-collection company.

To achieve this goal, surveys were conducted among the employees of the Miejskie Przedsiębiorstwo Oczyszczania (MPO) in Krakow (Municipal Cleaning Company). Opinions were obtained on problems that are related to waste collection in various types of buildings and mistakes that are made by waste producers during their segregation. Employees of the MPO also presented their opinions on the need to implement measures to improve the efficiency of waste segregation.

A literature study showed that many studies have indicated problems in the functioning of the waste-management system in the commune (Albin, 2018; Irla & Kowalska, 2022; Jakubiak & Śliwka, 2013). However, many works are devoted to this topic from the waste producers' perspective (Kalisiak-Mędelska, 2017; Kowalska et al.,

2020). Studies have been conducted on the behavior and decisions of waste producers and consumers who decide to deal with specific waste groups (Borkowicz, 2022; Królczyk et al., 2015). The literature on the subject also includes analyses, assessments of the satisfaction, and awareness of the inhabitants of Krakow regarding the waste-collection system. Citizens' preferences and expectations that were connected to the waste-management system were also examined (Kołcz & Ziółko, 2021). The research gap covers the area of waste management from the perspective of waste recipients; therefore, the authors of this article decided to conduct a survey among MPO employees who had direct contact with waste collection in the municipality of Krakow. Thanks to this, it was possible to list the emerging opinions and specify the most common problems that helped us formulate our conclusions and recommendations. The Krakow commune has its own specificity, but other municipal communes can also use the results of the research to improve their individual waste-management systems.

2. WASTE MANAGEMENT IN POLAND

Waste management in Poland has been going through changes; this is mainly due to the need to implement the new guidelines that were introduced by the European Union. When using the components of the natural environment, it is required that all entities follow the principles of sustainable development and strive to achieve the objectives of the circular economy, which is a modern model of management. Therefore, those entities that operate on the waste-management market are obligated to respect the guidelines and requirements that have been set at the national level (Dacko et al. 2018).

One of the most important regulations in waste management in Poland is the *Ustawa...* (2012); according to this, waste management should be carried out in such a way that ensures the protection of human life and health as well as the environment. The act also includes guidelines on the handling of individual types of waste and the obligations of the entities that produce and collect waste. In order to achieve the objectives that were set in the environmental protection policy, national and voivodeship waste-management plans are applied and updated accordingly, which are also regulated by the above-mentioned regulations act. Waste-management plans concern the waste that is generated in the area for which the plan is drawn up and imported into this area, including municipal waste, biodegradable waste, packaging waste, and hazardous waste. Waste-management plans also include waste-prevention measures, which are particularly carried out on the basis of the Krajowy Plan Gospodarki Odpadami [National Waste Prevention Program] (Lisowska, 2017; *Ustawa...*, 2012). It was also thought that these plans should create the basis for introducing modern methods for waste management – both in the field of technology and economics – and management – with the perspective of long-term solutions – resulting in a reduction in the amount of waste and limiting the negative effects on the environment (Albin, 2018).

Municipalities are responsible for municipal waste-management in Poland. This was the result from the provisions of the *Ustawa z dn. 13 września 1996 r. o utrzymaniu czystości i porządku w gminach* [Act of September 13, 1996, on maintaining

cleanliness and order in communes (as amended)] (1996). Waste management in municipalities covers the following areas:

1) waste collection and disposal,
2) cleaning up commune,
3) storage and disposal of waste.

Waste producers and property owners are also obligated to handle waste in accordance with the principles that were set out in (*Ustawa...*, 1996). These obligations included the selective collection of municipal waste that is generated by residents and companies in accordance with the requirements that have been set out in the commune's regulations and in the manner that was specified in the regulations that were issued on the basis of Art. 4a Par. 1. In Art. 6 Par. 3b of the act on maintaining cleanliness and order in communes, municipalities are required to achieve a level of preparation for the reuse and recycling of municipal waste. These levels have fixed weights that increase each year (Irla and Kowalska, 2022; *Obwieszczenie Marszałka...*, 2022):

- 35% by weight – for 2023,
- 45% by weight – for 2024,
- 55% by weight – for 2025,
- 56% by weight – for 2026,
- 57% by weight – for 2027.

2.1. Waste management in Krakow

The first mention of the waste-management system in Krakow dates back to 1884, when the "Comprehensive regulations for maintaining cleanliness and order for Krakow" were passed. In 1906, the City Cleaning Department was established, which changed its name to the City Cleaning Department in 1932 and again to the State Municipal Cleaning Company in 1951. On June 12, 1992, the city council adopted a resolution on the transformation of the Municipal Cleaning Company (Miejskie Przedsiębiorstwo Oczyszczania – MPO) in Krakow into a commercial law company that belonged to the municipality of Krakow (*Początki MPO Kraków sięgają 1866 roku*, 2023; *Utrzymanie czystości w sezonie zimowym*, 2023). Currently, MPO conducts analyses of the state of waste management; it performs tasks of maintaining cleanliness and order in the summer and winter seasons on public and internal roads as well as in playgrounds and open areas that are located on real estate that is owned by the municipality of Krakow or the state treasury (*Odbiór odpadów*, 2023; *Odbiór odpadów. Analiza*, 2023).

From April 1, 2022, all municipal waste is collected by a consortium of four companies that were selected through a public procurement procedure under an unlimited tender. The consortium of companies that collects municipal waste includes Małopolskie Przedsiębiorstwo Gospodarki Odpadami Sp. z o.o., PreZero Małopolska Sp. z o.o., REMONDIS Kraków Sp. z o.o., and FCC Polska Sp. z o.o. (*Sektory odbioru odpadów*, 2023). The waste collection by the listed companies in Krakow is determined by waste-collection sectors. Figure 1 shows the division of Krakow into waste-collection sectors.

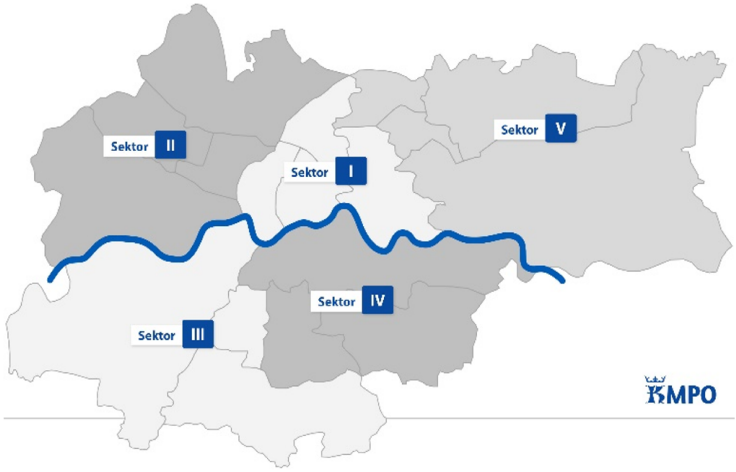

Fig. 1. *Division of Krakow into waste-collection sectors (Sektory odbioru odpadów, 2023)*

The basis for the selective collection of municipal waste in the municipality of Krakow is the collection of waste "at source." Since April 1, 2019, the selective collection of municipal waste have needed to take place according to the new rules. The new regulations introduce the segregation of waste into five fractions, which are assigned the appropriate colors of containers or in single-family houses – bags (Jakubiak & Śliwka, 2013). Detailed guidelines on the segregation of municipal waste in Krakow are presented in Table 1. Since November 1, 2020, all types of real estate in the municipality of Krakow have been required to selectively collect municipal waste. The fee for municipal waste management for residents who do not segregate waste is twice as high as for those who practice waste segregation. The additional fee is a kind of penalty for non-compliance with the requirements of the system (*Analiza stanu...*, 2023; Kołcz and Kołcz, 2021).

Table 1. *Guidelines for segregation of municipal waste in Krakow (Segregacja odpadów, 2023)*

Color of container or bag	Waste fraction	Itemization
Yellow	Metals and plastic	plastic bottles and food packaging, plastic bags, carrier bags, packaging for cleaning products, multi-material packaging (e.g., beverage cartons), metal cans, small iron scrap, polystyrene foam (non-construction)
Blue	Paper	grease-free packaging made of paper, cardboard, paper bags and sacks, newspapers and magazines, catalogs and leaflets, office paper, notebooks and books, wrapping paper

Table 1 cont.

Color of container or bag	Waste fraction	Itemization
Green	Glass	glass bottles and jars of beverages and food, glass packaging of cosmetics (unless they are made of permanently combined several raw materials)
Brown	Biodegradable	vegetable and fruit waste (peelings, etc.), food scraps (without meat and bones), coffee and tea grounds
Black	Mixed waste	greasy paper, soiled foils, used towels and paper tissues, varnished and foil-coated paper, hygiene articles (e.g., diapers), table glass, ceramics, porcelain, crystals, heat-resistant glass, mirrors, meat, bones and fish bones

Figure 2 shows the amounts of the collected municipal waste of the segregated fractions during the years of 2017–2021 in Krakow. The data shows that the greatest number of segregated fractions of municipal waste was generated in 2020. The largest amount of waste that was produced from plastics was collected, and there was about twice as much paper and glass waste. This may have been due to the introduced lockdown, resulting in the closure of catering establishments at the beginning of the COVID-19 pandemic. In 2021, the amount of plastic waste that was collected was the lowest since 2019.

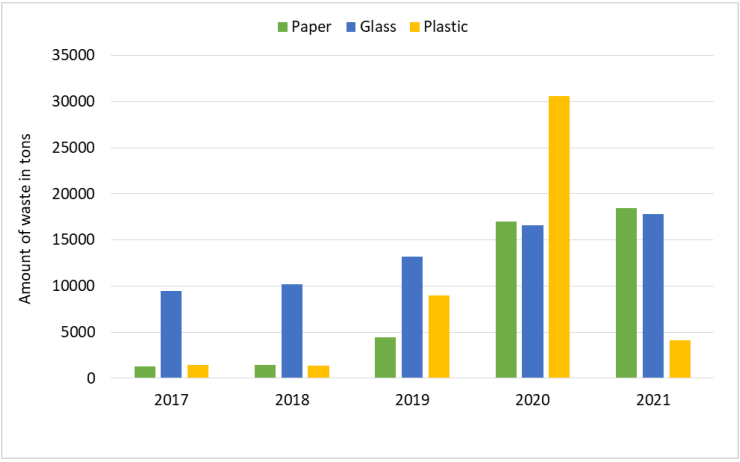

Fig. 2. *The amount of collected fractions of segregated municipal waste in tons in Krakow during period of 2017–2021 (Bank Danych Lokalnych GUS, 2023)*

Several factors contribute to this situation. The municipality of Krakow applies the Integrated Municipal Waste-management System, which covers properties that are

inhabited by residents and properties that are not inhabited by residents, which facilitates the functioning of the system. The use of educational programs and the effective flow of information (e.g., online waste finder) certainly contribute to the increase in the amount of segregated waste (*Analiza stanu...*, 2023; Zarębska and Zarębski, 2018). Another challenge for waste management is the needs for better segregation and increasing the recycling of plastics that have resulted from the EU regulations. Since January 1, 2021, the EU budget has been fed with a fee for the plastic packaging that is produced in a member state that has not been recycled (Directive 94/62/ECC, 2023). Therefore, it is in the interest of all municipalities to increase their amounts of recycled plastic packaging waste.

Waste management in Krakow is planned for a specific period of time (reports on waste-management plans are presented for a period of one year), taking the specific needs and the need to introduce changes in a developing city into account. Waste-management plans are based on the principles of sustainable development, and society should be involved in their development (Wieczorek & Siekierski, 2021). The waste-management plan refers to the provisions of the Environmental Protection Program for Małopolskie Voivodeship, which indicates ordering waste management, among others, among the three main ecological priorities. In the case of Krakow, waste-management directions are defined locally on two levels: in the waste-management plan for the Lesser Poland region, and in the waste-management plan for the city of Krakow (Jakubiak & Śliwka, 2013).

The problems of waste management in Krakow were dealt with by Kołcz and Ziółko, who made an attempt to evaluate it. The study was conducted among the residents and concerned the satisfaction and awareness of the inhabitants of Krakow in relation to the waste-management system in the municipality of Krakow. Based on the answers that were obtained, it was found that the surveyed residents noticed many problems in the waste-collection system. The problems were the technical organization and the information environment (Kołcz & Ziółko, 2021).

3. MATERIALS AND METHODS

In order to achieve the aim of the article (which was to assess the effectiveness of the waste-management system in Krakow), it was decided to conduct a survey among employees who were directly involved in waste collection. They were supposed to show the problems that were faced by the recipients. The municipality of Krakow was selected as the research object, in which 802,583 people lived in 2021 according to the data from Statistics Poland. This population produced 345,720 tons of municipal waste (Bank Danych Lokalnych GUS, 2023) . The waste that was collected selectively accounted for 31% of the municipal waste. Nearly 100% of the residents and businesses were covered by the waste collection.

In order to obtain materials for the analysis of the municipal waste-collection system of recycled fractions, individual surveys were conducted in May 2021 with the employees of MPO Sp. z o.o. in Krakow. The study involved 41 employees who dealt directly with the collection of municipal waste. These were only men with primary and vocational educations.

The surveys that were conducted among the employees of MPO Krakow Sp. z o.o. allowed for the identification of problems that were related to waste collection and the formulation of conclusions that could be used by the municipality of Krakow to improve the functioning of the waste-management system. The results were developed in the Microsoft Excel program.

The questions that were asked in the survey concerned the segregation of the waste fractions: plastic and metal, paper, glass, biowaste, and mixed municipal waste. The following questions that were asked in the survey are presented in Table 2.

Table 2. *Questions asked in survey to employees of MPO in Krakow*

Question	Evaluation
1. How do you assess the waste segregation carried out in single-family buildings? (Please rate from 1 to 5, where 1 means the worst and 5 means the best).	Likert scale 1–5
2. How do you assess the waste segregation carried out in multi-family buildings? (Please rate from 1 to 5, where 1 means the worst and 5 means the best).	Likert scale 1–5
3. In which types of buildings or estates is the correctness of the segregation the best? (Please rate from 1 to 5, where 1 is the worst and 5 is the best).	Likert scale 1–5
4. What are the irregularities in the segregation of waste in the municipality of Krakow? (Please rate from 1 to 5, where 1 means the worst and 5 means the best).	Likert scale 1–5
5. Are the bins for different waste fractions color-coded correctly? (Please rate from 1 to 5, where 1 is the worst and 5 is the best).	Likert scale 1–5
6. Which of the listed waste fractions are most often segregated in the wrong way? (Please rate from 1 to 5, where 1 is the worst and 5 is the best).	Likert scale 1–5
7. Should there be inspections of the correctness of the municipal waste segregation by residents and companies?	Answers: Yes, No, I do not know

The surveyed employees of MPO Sp. z o.o. in Krakow answered all of the questions that were posed in the survey. The questions in the survey were consulted with one of the employees of MPO in Krakow. The results of the surveys were presented in the form of bar graphs in relation to the individual survey questions. In the Results chapter, Figures 3–9 present the respondents' answers to the questions in Table 2. Note that the charts presented in Figures 3–9 express individual levels of the Likert scale with different colors and the numbers above the individual columns express the number of people choosing a given level of the Likert scale. The lowest level of the Likert scale corresponds to the worst rating, and the highest level corresponds to the best rating.

4. RESULTS

Below are the numbers of the responses to the questions in Table 2.

1. How do you assess the waste segregation carried out in single-family buildings?

Figure 3 shows that the vast majority of the respondents assessed that the segregation of waste of all fractions in single-family houses is carried out in a very good or good way (5 and 4 ratings). This may be due to the fact that the inhabitants of single-family houses have individual rubbish bins located on the premises to which only the inhabitants of the house have access, and the waste producers can be easily identified.

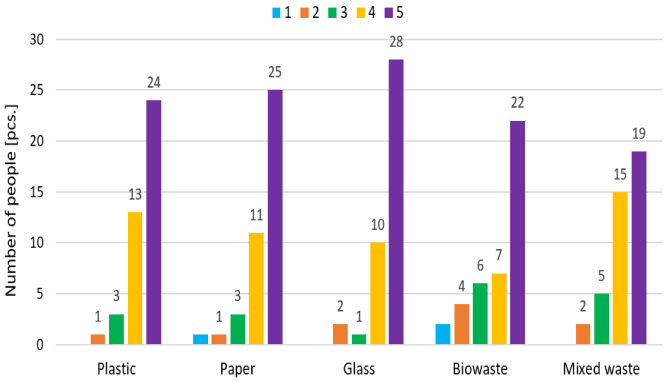

Fig. 3. *Evaluation of effectiveness of waste segregation in single-family buildings – Question No. 1*

2. How do you assess the waste segregation carried out in multi-family buildings?

As shown in Figure 4, the answers of the respondents to this question differed significantly from the answers to Question 1.

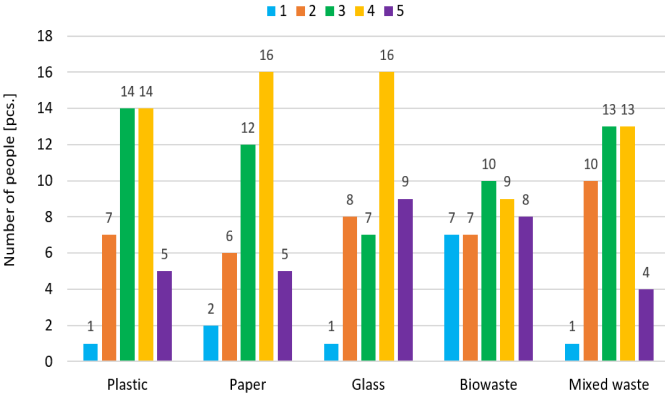

Fig. 4. *Evaluation of effectiveness of waste segregation in multi-family buildings – Question No. 2*

Most of the respondents assessed that there were mistakes in the segregation of fractions of plastic, paper, glass and mixed waste (scores 3 and 4). The segregation of biodegradable waste was rated the worst (scores 1, 2, and 3). In multi-family houses, residents throw waste into containers that are located in common rubbish bins, where there is no possibility to control the correctness of the segregation. Other problems are the insufficient number of containers for individual waste fractions, the poor lighting of rubbish bin shelters, dirt, insects, and odors. These factors may make residents reluctant to segregate waste and want to throw waste into containers as soon as possible in order to have the briefest-possible contact with the inconvenience.

3. In which types of buildings or estates is the correctness of the segregation the best?

As shown on Figure 5, three-quarters of the respondents assessed that the most correct waste segregation (score 5) was in single-family houses. This rating was due to the fact that homeowners personally declare whether they will segregate waste or not as well as the number of residents. On this occasion, they received materials informing them about proper segregation. In the case of single-family houses, it is also possible to determine the responsibility for poor segregation. The correctness of waste segregation in closed housing estates was assessed by ¾ of the respondents as medium (3 and 4 ratings). In such housing estates, containers for segregated waste are located in closed garbage shelters, and only residents have access to them. Segregation was rated the worst in non-gated housing estates, where the rubbish shelters are open and the containers for segregated waste (e.g., bell-type) are placed next to the rubbish sheds. For these reasons, various types of waste can be thrown into them by random people.

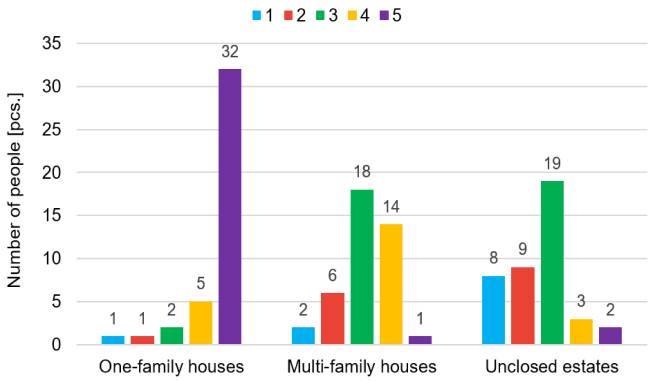

Fig. 5. *Evaluation of effectiveness of waste segregation in multi-family buildings – Question No. 3*

4. What are the irregularities in the segregation of waste in the municipality of Krakow?

Figure 6 shows that the respondents assessed that the biggest problem was throwing away biodegradable waste together with bags for this waste, throwing waste into

bags for other waste fractions, and throwing dirty non-segregated packaging into the wrong containers. Contamination of the waste fraction results in additional costs that are related to the preparation for their management. The smallest irregularities concerned poorly tied bags for segregated waste and damaged bags for segregated waste.

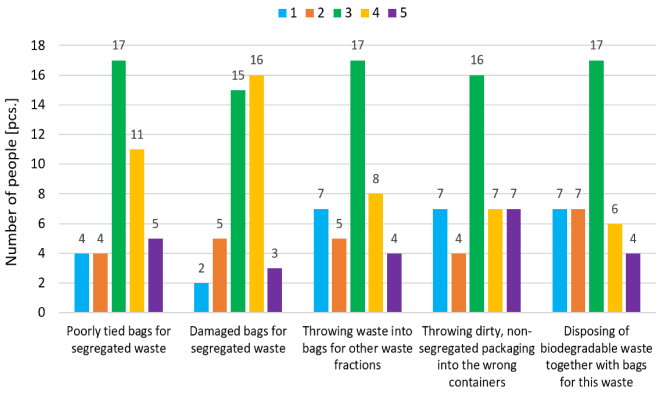

Fig. 6. *Evaluation of effectiveness of waste segregation in multi-family buildings – Question No. 4*

5. Are the bins for different waste fractions color-coded correctly?

Figure 7 shows that almost three-quarters of the respondents believed that the containers for plastic and metal, paper, glass, and mixed waste were properly labeled.

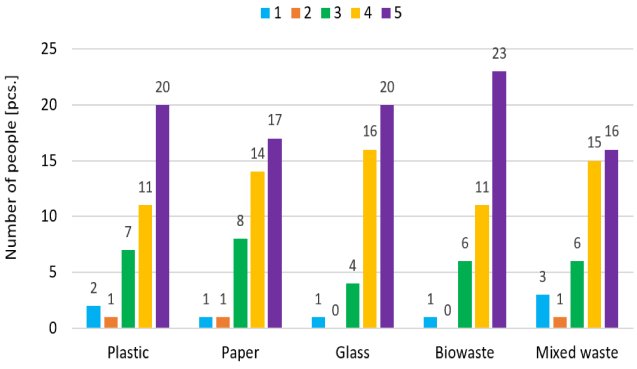

Fig. 7. *Evaluation of effectiveness of waste segregation in multi-family buildings – Question No. 5*

The labeling of containers for biodegradable waste was rated even better (grades 4 and 5), as is shown in Figure 7. Since July 1, 2017, the Uniform Waste-segregation System (*Obwieszczenie Marszałka...*, 2022) has been implemented throughout the

country; according to this, waste fractions have been collected in bags that are marked with the appropriate colors.

6. Which of the listed waste fractions are most often segregated in the wrong way?

Figure 8 shows that the sorting of biodegradable waste received the worst scores (scores 1 and 2). This may be due to the fact that, although the containers for biodegradable and mixed waste have the correct colors (brown and black), they are difficult to distinguish in poorly lit rubbish sheds. This was confirmed by the assessment the of mixed-waste segregation. It was assessed that the least irregularities were among the plastic and metal, paper, and glass fractions, which have distinctive colors (yellow, blue, and green, respectively). These colors have been assigned to these waste fractions since the introduction of the new regulations (i.e., since 2013), and the obligation to segregate biodegradable waste came into effect only on July 1, 2017 (*Obwieszczenie Marszałka...*, 2022)

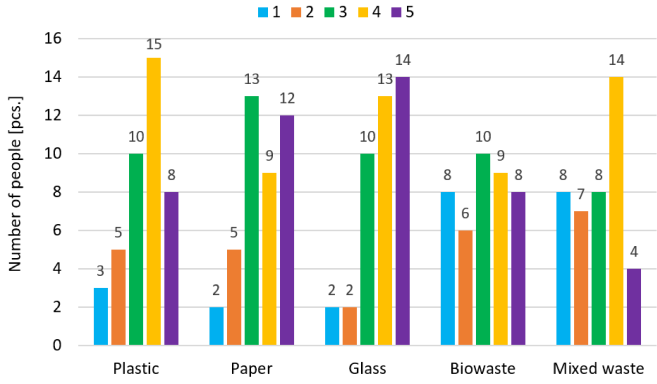

Fig. 8. *Evaluation of effectiveness of waste segregation in multi-family buildings – Question No. 6*

7. Should there be inspections of the correctness of municipal waste segregation by residents and companies?

Figure 9 shows that the majority of the respondents (68%) considered it necessary, while only 10% were against it. This might be a tool that could improve the level of preparation for the reuse and recycling of municipal waste (*Calculation of the level of preparation and recycling of municipal waste*, 2023). The greatest effectiveness of such activities would be among those people who live in single-family houses and have individual dumpster sheds, as penalties for incorrect sorting would be imposed on specific households. Inspections that are carried out in common waste containers that are located in housing estates could result in penalties being imposed on all of the waste producers from a given building. There would have to be an awareness of collective responsibility; unfortunately, this is a problem.

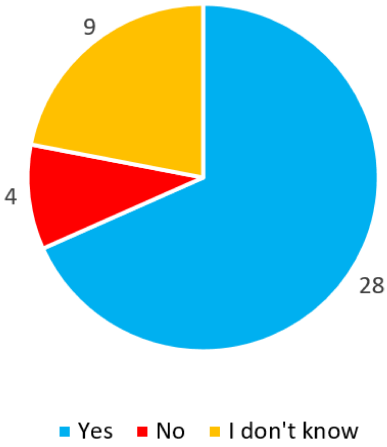

Fig. 9. *Evaluation of effectiveness of waste segregation in multi-family buildings – Question No. 7*

5. DISCUSSION

The European Union undertakes a number of initiatives in the field of changes in the area of waste management, obliging member states to improve their waste-management systems. These concern fulfilling the objectives of the circular economy, which will result in lower gas and dust emissions as well as climate neutrality (Kulczycka, 2018); this will help meet the EU's environmental objectives. Based on the principles of sustainable development, the adopted policies and objectives of the EU require the implementation of regulations on a macro scale (i.e., at the institutional level) as well as at the regional and local levels (i.e., in EU countries [https://sdgs.un.org/goals]). Therefore, it is important to organize, administer, and implement municipal waste-management plans and create integrated waste-management systems while respecting local development strategies.

The development strategy for Krakow through 2030 that was developed in accordance with the smart city concept takes the concept of a smart environment into account regarding the modernization and expansion of municipal infrastructure, including the development of the infrastructure of a comprehensive municipal waste-management system (Gorzelany and Lorek, 2018; *Kraków przyszłości*, 2023). Despite the adopted system assumptions, there are still problems being reported by waste producers and their recipients; these have been presented in this analysis and in the survey that was conducted among the employees of MPO in Krakow. Solving the problems that are related to segregation is a complex issue that should be addressed to all of the participants in the waste-management system. Therefore, informing about the functioning of the waste-management system should be an important part of the activities of those departments that are responsible for waste management (Kowalska et al., 2020). Also, educating society in the field of waste reduction, the selective collection

of recyclable materials, or creating a "fashion" for more durable and environmentally friendly products can significantly contribute to changing such consumer behavior and activating the society to participate in activities that are aimed at improving waste management. A necessary condition is to provide appropriate a "participant-friendly" technical infrastructure; i.e., one that is properly located and facilitates waste segregation (*Poradnik...*, 2002). This applies not only to waste-collection sites but also to the entire spatial order, which takes the needs of waste management into account. Creating such an order is a task for architects who design new roads, housing estates, and buildings (Szewczyk & Chrobak, 2021).

6. CONCLUSIONS

Waste management in Krakow is carried out in accordance with the guidelines that have been set for EU member states and in accordance with the principle of sustainable development. This is aimed at reducing the amount of unsorted waste in favor of sorted waste that is subject to recycling. The actions that have been taken include covering all of the residents of Krakow with the waste-collection system at the point of waste generation and enabling the segregation of municipal waste in single-family and multi-family houses. As part of the actions that are taken, municipal waste-recycling levels are reached every year, and the Municipal Cleaning Company LLC helped to achieve it.

A survey was carried out among MPO employees, which made it possible to evaluate the system from the point of view of the waste-collection company. The conducted analysis showed the scale of the problem of waste management in Krakow. The most difficult situation is in the housing estates of multi-family houses, where, there is often no space to set up the number of containers that are required by law due to too-small rubbish sheds. The consequence of this is throwing waste into the wrong containers, which promotes the development of pathogens and attracts rodents. According to the employees of Krakow MPO who collect the waste in these housing estates, the worst situation concerns the segregation of biodegradable waste. One of the reasons may be the similar colors of the mixed waste (black) and biodegradable (brown) containers. A change of colors should be considered, which would improve their recognition in poorly lit rubbish sheds. Designers of new housing estates should take waste-management regulations into account and design garbage sheds or other waste-collection sites so that residents can segregate their waste products properly.

The basis for the operation of each system is control; therefore, those employees that collect waste should have the right to control the correctness of the waste segregation and report any irregularities to the municipal services. This possibility should be considered and combined with a system of possible financial penalties.

The topic of improving waste management is current and important; this is why the authors will develop it in further research. Improving waste separation is key to achieving the better recycling levels that have been imposed by the European Union. The continuation of the research will cover issues that are related to the fraction of biodegradable waste and an analysis of the possibility of increasing their recycling levels in communes.

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