DOI:10.17951/h.2024.58.3.51-68

ANNALES
UNIVERSITATIS MARIAE CURIE-SKŁODOWSKA
LUBLIN – POLONIA

VOL. LVIII, 3 SECTIO H 2024

IZABELA KUDELSKA

izabela.kudelska@put.poznan.pl
Poznań University of Technology. Faculty of Engineering Management
2 J. Rychlewski St., 60-965 Poznań, Poland
ORCID ID: https://orcid.org/0000-0002-8717-4315

KRYSTIAN JĘDRZEJAK

jedrzejak_krystian@o2.pl
PHU IGLOO
5 Jałowcowa St., 63-740 Kobylin, Poland
ORCID ID: https://orcid.org/0009-0000-4848-6415

Methodology for Designing Spatial Layout of a Warehouse in the Context of Sustainable Development

Keywords: warehouse; layout; warehousing; design; efficiency; sustainable design

JEL: D2; D3

How to quote this paper: Kudelska, I., & Jędrzejak, K. (2024). Methodology for Designing Spatial Layout of a Warehouse in the Context of Sustainable Development. *Annales Universitatis Mariae Curie-Skłodowska, sectio H – Oeconomia*, *58*(3, special issue), 51–68.

Abstract

Theoretical background: The literature analysis focuses on the importance of spatial design of warehouses, especially the retrieval zone. Research shows that warehouse layout has a key impact on operational efficiency, especially in manual order picking. The authors discuss various approaches that are mainly aimed at minimizing the average distance traveled by warehouse employees when picking orders. Other studies also include warehouse workers' movements and operations planning. The authors note that existing research focuses mainly on operational efficiency, ignoring social and environmental aspects. Hence,

there is a need to develop a methodology that will take into account these additional aspects of designing a sustainable warehouse.
Purpose of the article: The article in the context of scientific research aims to present the methodology of designing a spatial warehouse system in terms of sustainable development. In a practical context, a tool for assessing the effectiveness of sustainable design was developed.
Research methods: A case study was chosen as the research method. Observation and interviews with employees were used. These methods allowed for a better understanding of the analyzed issue and occurring phenomena. In addition, the methods used allowed to verify the developed method of spatial design of the warehouse in terms of sustainable development.
Main findings: By achieving scientific and practical goals, the article can contribute to promoting sustainable design in business and architectural practice and contribute to building a more sustainable and effective work environment.

Introduction

In the first half of 2020, the warehouse market in Poland recorded further growth. According to the report, which is carried out by JLL, in terms of new demand Poland was the second most active country in Europe and the only one to have recorded a visible increase in comparison to the same period of the previous year – by as much as 30% (Polkowski & Kotowski, 2020). During 2023, there was a significant decrease in demand for industrial-logistics space. However, in 2024, the stabilization of the economic situation, the construction of another deep-water quay at the Baltic Hub container terminal, the expansion of the port in Świnoujście, and the expansion of the external port in Gdynia will allow for increased investor activity. Economic forecasts provide a basis for improving the level of investment in the industrial-logistics market (Bank.pl, 2024).

The demand for warehouse space is closely related to the functioning of the supply chain. Supply chain integration requires collaboration in terms of information and organization of process and material flows (Koliński & Werner-Lewandowska, 2021). Within the supply chain, warehouses play a crucial role in storing, consolidating, distributing, and managing inventory. As the supply chain evolves, businesses seek new solutions to enable better customer service and minimize costs. The high-quality logistics is an important component of effective supply chain management and in the enterprise itself (Rahman, 2006).

Warehouses consume huge amounts of resources. Therefore, processes should be reorganized to become more environmentally friendly and at the same time efficient and economical. Hence, responsible resource management is also pivotal to fulfill the Goal 12 UN SDG "Responsible consumption and production" (Golińska-Dawson et al., 2021). According to the research of Ma and Mao (2019), an important issue is the analysis of the material flow and the route of logistics operations. One of the most important ways to achieve the required efficiency of both the facility as well as the warehouse process itself is to shape its basic functional areas properly. A warehouse is more efficient if it is designed correctly. In this way, it can help you quickly meet your customers' needs. In addition to proper design of the warehouse layout and configuration, the warehouse process plays a key role in increasing its efficiency. The warehouse layout and process work together, thereby increasing the efficiency of the warehouse as a whole (Mohamud et al., 2023). The proper selection of the storage technology may lead to a significant acceleration of warehouse processes. Improper management of warehouse functions and the warehousing process may adversely affect the economic profits of the entire enterprise. This will happen through the generation of excessive inventories (immobilization of large amounts of capital), stock interruptions, i.e. loss of sales (Marziali et al., 2021; Lee et al., 2018). The article attempts to review and evaluate the state of the existing in the literature research concerning primarily the operation of the warehouse, focusing on the design of the warehouse (in spatial layout).

The literature research shows that research focuses mainly on improving warehouse space in order to increase operational efficiency. Therefore, the research goal of this article is to present the methodology for designing a spatial system of warehouse in terms of sustainable development. The practical aim of this article is to develop a tool for assessing the effectiveness of sustainable design. The presented methodology will help designers assess the effectiveness of the applied sustainable design practices.

Therefore, the content of the article consists of the following chapters. Chapter 1 presents the research methodology along with the research question. Chapter 2 contains a literature analysis, while the next chapter presents the methodology of spatial design from the perspective of sustainable development. The fourth and fifth chapters cover the research and discussion. The research is conducted within the company to verify the correctness of the developed methodology. The final chapter of the article includes conclusions and directions for further research.

Research methodology and research subject

At this point, a detailed methodology of the conducted scientific research will be presented, aimed at showcasing the design method of the existing warehouse space considering social and environmental aspects. The research approach consisted of the following three steps.

Step 1: Literature analysis. As a result of conducting a literature review on the subject, a research gap was identified. Identifying the research gap was an important step in the research process because it pinpointed areas requiring further development and served as a starting point for formulating research questions and developing the methodology for designing warehouse space in the context of three pillars of sustainable development. The research question posed after conducting the literature analysis is: RQ 1: What design practices can be used to balance economic goals with the needs of employees and environmental protection?

Step 2: Development of spatial design methodology in relation to the three pillars of sustainable development.

Step 3: Verification of the developed methodology. The authors chose a case study as their research method. Using a case study, the authors verified the presented warehouse space design methodology in the context of the three pillars of sustainable development.

This method provides a better understanding of the analyzed issue and occurring phenomena. The case study was chosen for a company that operates in Poland. An important argument, which stood in favour of the chosen case study, was certainly the possibility of conducting the research. The research was carried out in a company that disposes refrigeration electromechanics. The plant offers a wide range of services, starting from refrigerator repair, through installation of chillers, installation of air conditioning devices, regeneration of refrigeration equipment. A warehouse with parts for shop fittings is considered in the research. This warehouse is only rented by the company, which prevents large investments from happening. The warehouse is responsible for the overall shipment of basic equipment elements to both new and renovated facilities.

In this step, observation and interview were also used to conduct the research, and measurements were made that related to three goals identified in the methodology. The observation was continuous. Interviews were conducted with warehouse employees. These interviews were structured and personal.

Literature review

The work on shaping the warehouse space includes primarily the picking zone. The design of the warehouse layout has a large impact on warehouses for manual order picking. These parameters play an important role in determining the length of the route that is covered during picking (Roodbergen et al., 2008). The length of the route has in turn an impact on the operating costs of the warehouse. Therefore, Shqair and Altarazi (2014) developed an agent-based model in order to simultaneously study the impact of the order size in parallel with the different parameters of the layout. Roodbergen and Vis (2006) were similarly working on the approach to determining the layout of the order picking area in the warehouse in order to minimize the average distance of the staff who picked. Caron et al. (2000), on the other hand, presented an approach to the layout of the picking area in low-level pick-to-part systems using COI and random storage rules. Many warehouses use the arrangement of shelves, therefore an important parameter is to calculate the distance between positions in the warehouse, which does not always have a standard arrangement. Such studies used dynamic programming (Žunić et al., 2018).

In order to determine the optimum design parameters of the warehouse, two variants of the warehouse's spatial arrangement were compared, taking into account both service costs and costs related to the area as well as perimeter of the warehouse (Bassan et al., 1980). However, a very broad research covering the parameters of various types of storage (rack and rackless) was undertaken by Matson and White (1982). The literature also deals with the topic related to the requirements for the arrangement of warehouses in which the distribution was examined and equations for their dimensioning were derived (Berry, 1968).

The topics of spatial design of a high-bay warehouse are also addressed (Ashayeri et al., 1985). Such systems are very expensive investments and at the same time difficult to modify. The same topic was later taken up by Lerher (2006) and Kawęcki and Gola (2022). The following elements of the design were presented in a breakdown into such processes as: storage, transport, order picking of storage and retrieval systems (AS/RS). Single-channel systems and multichannel systems were compared with each other. In order to shorten the average transport time and increase capacity, the advantages of a class-based multichannel system were deployed. Within the research there was also a discussion on the problem of selecting the height of the rack outlet. The criteria taken into account are primarily space and costs (Lee et al., 2005). Huertas et al. (2007) were considering in their research the warehouse arrangements. However, a warehouse is not only a storage or picking area. In their publication, Lin and Sharp (1999) addressed the qualitative and quantitative indicators used to assess the spatial arrangement.

Artificial intelligence algorithms were used in the research on the design of the warehouse layout. Muharni et al. (2019) used the particle swarm algorithm to optimize the distribution at the lowest cost of material handling. Similar studies were also carried out by Sooksaksun and Kachitvichyanukul (2010), in which the objective function was to minimize the average travel distance. Multilevel configurations of warehouse racks were also proposed, in which the objective function was the annual minimization of transport costs and the tool was the particle swarm optimization algorithm (PSO) (Önüt et al., 2008). Another important area related to warehousing are the works on the routes of the picking worker and the planning of warehouse operations, as well as on the distribution of products in the storage area. Gu et al. (2007, 2010) have shown an extensive review and evaluation of the processes in the picking area, including route assignment. A planning approach that can ensure efficient management of warehouse processes was presented by De Koster et al. (2007). A typical planning approach (to e.g. routes in the picking process) was presented by Vanden Berg (1999) and in the work of Kudelska and Niedbał (2020).

Literature analysis indicates that previous studies have mainly focused on operational efficiency and its improvement. However, despite the rich background in operational efficiency, little attention has been paid to methods incorporating social and environmental aspects of warehouse space design. Therefore, there is a need for research that considers additional aspects.

A method of designing a spatial layout

The design of warehouse space should be holistic. This means that the design methodology should consider all aspects to ensure sustainable development and optimal warehouse functioning.

Proper organization of space depends on various factors: the technological layout of the warehouse, the size and equipment of the storage area, the need to separate the picking zone, work methods, and warehouse equipment. Combining these elements requires detailed analysis as they impact the investment and operational costs of the warehouse. Many elements within the warehouse must harmonize with each other. This compatibility requires the warehouse space to facilitate uninterrupted employee work and material movement. Correct organization of both the warehouse space and warehouse infrastructure is important; otherwise, basic warehouse tasks and the warehouse process itself may be disrupted.

Transitioning from design methodology to warehouse space organization is a significant step in optimizing logistical processes. Therefore, warehouse space, being an integral part of the supply chain, plays a crucial role in efficient inventory management and warehouse operations execution. However, to achieve maximum warehouse efficiency, it is important to apply a design methodology that considers both functional, ergonomic, and environmental aspects. This methodology requires interdisciplinary analysis of business requirements, process analysis, and alignment of strategies with specific needs. Warehouse design activities form a platform that requires a holistic, iteratively improving approach, taking into account the perspective of end users, namely warehouse employees. The methodology related to the warehouse space design process, incorporating a holistic approach, is presented in Figure 1.

The method presented in Figure 1 comprises several key stages. The first step is to identify all operations and activities occurring in the warehouse process. Next, it is necessary to create a warehouse and material flow map. These maps encompass tracking where and how goods are stored, moved, and processed in the warehouse. The next stage is to assess the warehouse in terms of the three pillars of sustainable development, namely: economic growth, environmental protection, and employee well-being, as depicted in Figure 2.

Utilizing the pillars of sustainable development in relation to warehouse space design allows achieving a balance between economic growth, environmental protection, and social responsibility. Based on data analysis, proposed solutions aim to efficiently utilize resources, minimize natural resource consumption, or reduce greenhouse gas emissions, and effectively manage waste while ensuring fair working conditions and employee well-being.

After accepting the improvement proposal, implementation is an important step. These may be gradual modifications that will focus on only one improvement proposal or a few minor changes. However, after implementing the changes, it is important to assess whether the improvements have brought the expected results in terms of the pillars of sustainable development.

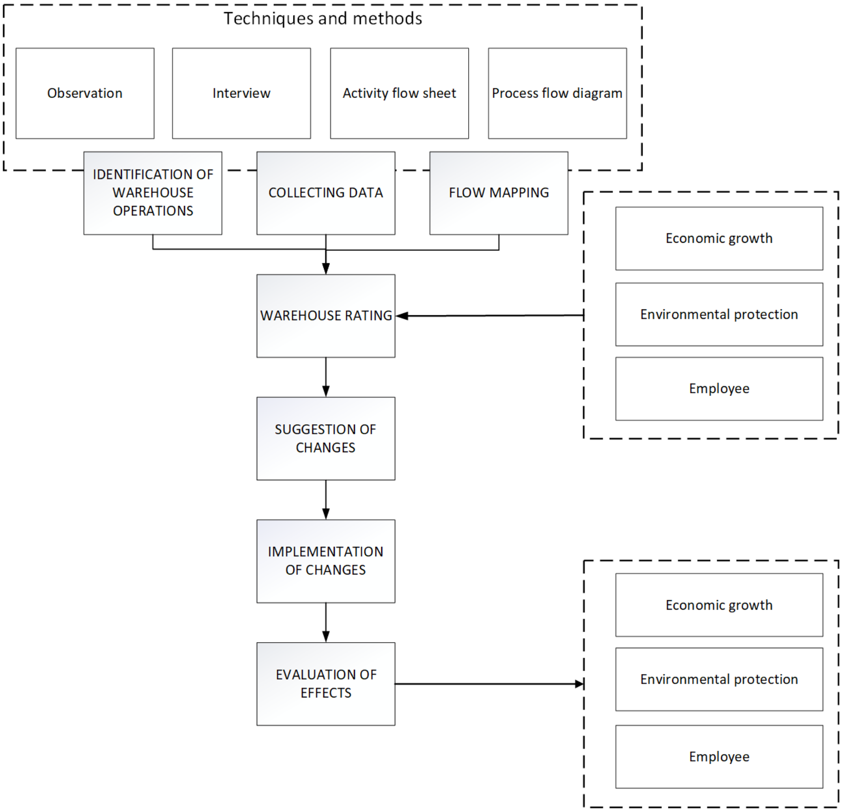

Figure 1. Methodology for designing warehouse space

Source: Authors' own study.

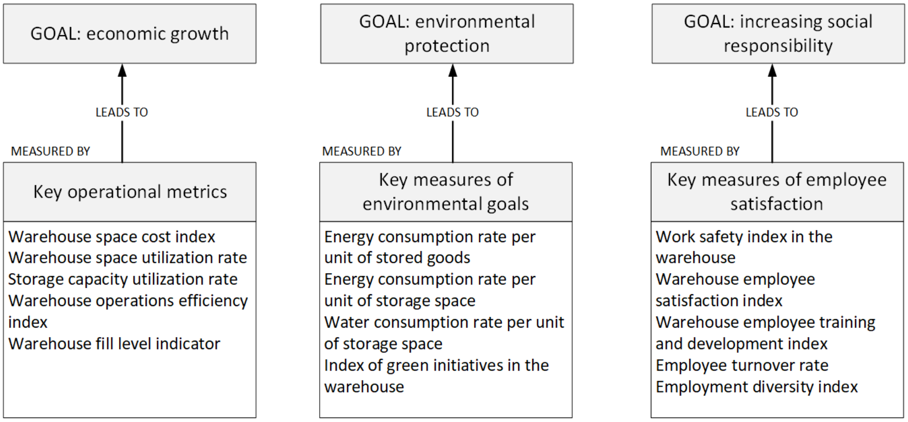

Figure 2. Indicators in the context of sustainable development when designing warehouse space

Source: Authors' own study.

Subject of research – current state of the warehouse

The spatial development of the analyzed warehouse facility assumes storage of EUR type pallet cargo units directly on the floor without the possibility of stacking. A characteristic feature of the analyzed object is also its unusual roof structure. It is in the central part of the warehouse where its height is at its greatest, which distinguishes the object from other warehouse buildings, which usually have a flat roof. This feature of the object determines the fact that the roof has a pointed layout. Moreover, the fundamental space has no distinctively separated storage areas. A sketch of the analyzed warehouse is shown in Figure 3.

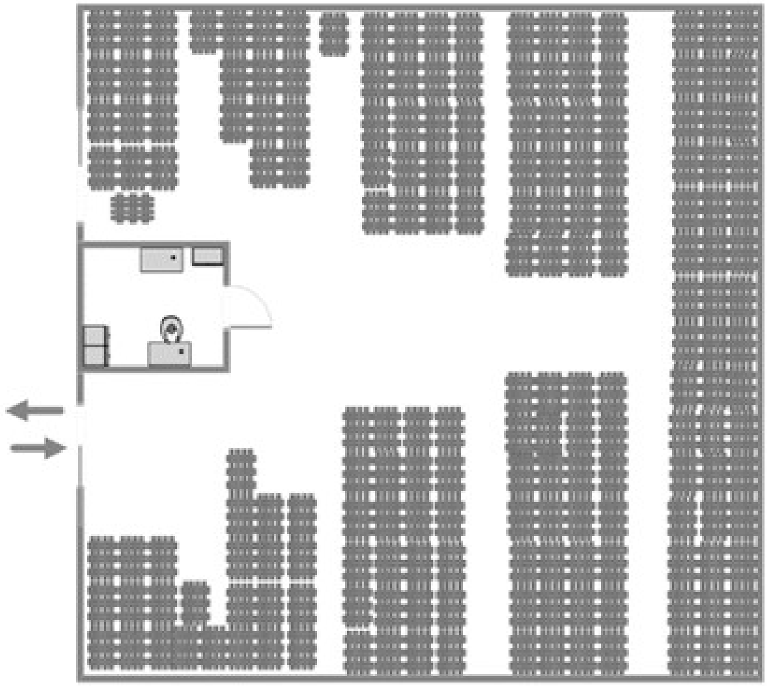

Figure 3. Drawing of the analysed subject – situation before the change

Source: Authors' own study.

During the interview, employees confirmed the conclusions of the conducted observations. Oftentimes during the picking of sets from the group of the aforementioned prototypes, other completed orders (counting up to several dozen pallets) must be transported outside in order to prevent them from hindering further work. These activities take up daily about 30% of the working time that is available during the day. During the transport of elements outside the warehouse or in another part of the warehouse, there is a lot of damage as a result.

In the current spatial setting there is no possibility of direct access to each pallet cargo unit. This requires frequent changes of the means of transport. This means that the employee has to make more additional work movements, which also leads to longer picking times. Taking the products out of the warehouse resulted in an extension of the order completion time for the customer. Extending picking times and damage caused during manipulation had a negative impact on the logistics of customer service.

The analyzed enterprise is developing, therefore, there is a need for more warehouse space. And nowadays, the issue related to the proper layout of warehouse space is becoming more and more important. Correct design of all elements of the warehouse process and efficient organization of the warehouse determine the strength of the activities conducted by the company and its co-operator.

New layout of warehouse and discussion

The technological system of the analyzed warehouse should remain bag-oriented. In this way the process of receipt and release will be carried out by separate warehouse gates. Thanks to such a technological system both the reception area and the release area should be separated by a socio-administrative building, the location of which will remain unchanged. The location of the office room will help with the observation and control of internal warehouse activities, carried out both in the reception area and the release area. A draft of the proposed solution is presented in Figure 4.

In reference to the storage area, what will increase the number of pallets stored will be the use of warehouse racks. Using this type of storage devices will also increase the quality of stored goods. Thanks to the proper protection, it will be possible to stack stocks according to their types or dimensions, which will ensure the full use of the available warehouse racks. Out of the three available groups of racks, due to the height of units stored, it is advised to use their height up to 6 m. This height is supported by the majority of lift trucks, and most importantly, there is no need to change the device.

Thanks to the possibility of configuring the layout of individual sockets in this type of racks, it is possible to adjust their position to individual operations. The arrangement of pallet racks in the storage area can be either freestanding or as single or double rows of racks. Strings of racks can be operated from both sides. It is important to provide access to each of the rack sockets. It is proposed to use universal row pallet racks in the analyzed company.

The number of pallet places for this rack is 9, with the distribution of 3 places on each level. The levels also include floor, on which loading units of the highest weight can be placed, e.g. bases for a column profile, supports or price bars.

The second method of storing goods will be the block storage method. This is based on stacking stocks without preserving a direct access to either the units or the whole stacks of them. The rack shelves will be stored in this way due to their adaptation to stacking on one another and their column profiles. Appropriate protection with special band and cardboard corners will make the pallet load units formed in this way able to withstand heavy weight.

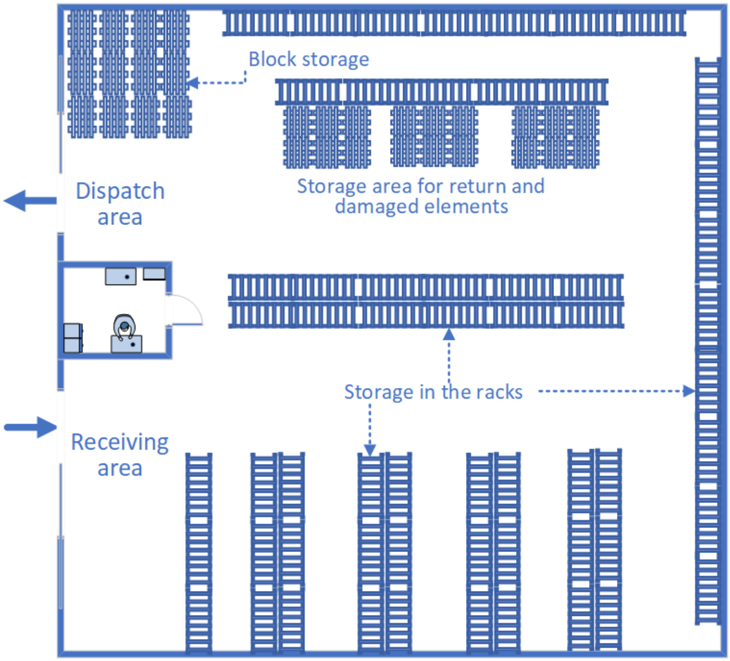

Figure 4. Draft on the analyzed warehouse with changes

Source: Authors' own study.

The observation shows that the quantity of this assortment item in the order is often recurring, therefore storing it near the issue area will minimize the transport activities. The assumption is that the quantity of this item often oscillates around 200 or 300 pieces per order per single outlet. This means that it is easier for the cart operator to work as he takes such a unit on average from 2 to 3 times during loading. Located close to the dispensing area, it will also reduce time.

In order to achieve greater operational efficiency, the warehouse should better organize the warehouse process using resources, technologies and the spatial layout of the warehouse. Optimizing the spatial layout of the warehouse is to create a functional design of the warehouse facility, which includes both technological, process aspects and employee well-being and environmental protection.

The capacity of the warehouse before the change was 494 pallet loading units, as shown in Figure 5. After the change it can be increased to 1,132 units. The newly developed warehouse space would allow to increase the potential of the existing storage facility, which has not been used so far.

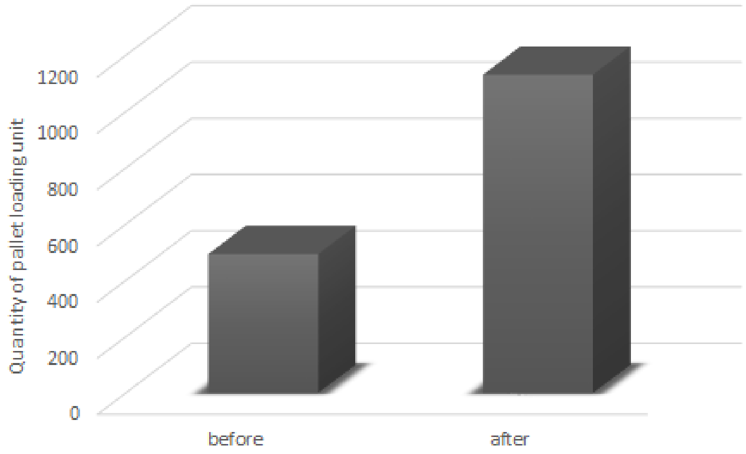

Figure 5. The capacity of the warehouse before and after the storage space

Source: Authors' own study.

With a capacity of 108 pallets (block storage method), the warehouse will be able to accommodate nearly four complete islands of racking equipment for new and regenerated commercial buildings. This solution will contribute to the increase of safety in terms of storage of goods and limit too frequent manipulation of them as a result of unfavorable location between the rows, in which the accumulated stock is stored. Thus, the indicator of the storage capacity utilization increased, as shown in Figure 6.

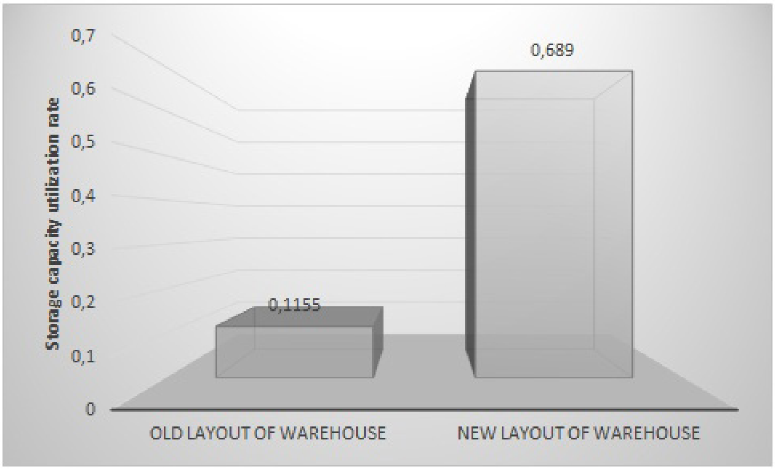

Figure 6. Capacity utilization rate

Source: Authors' own study.

The proposed scheme of the transport route inside the warehouse will increase the level of security and thus improve the flow of loading units when handling deliveries and shipments from and to the warehouse and the number of handling activities will be reduced.

Rack elements are stored directly on the floor in cardboard boxes on pallets, from which an employee takes the required number of pieces manually. In the further part of the work, based on the list received, the employee completes the rack elements by stacking them on a pallet. The employee uses a hand pallet truck for the activities related to the movement of the currently completed loading unit inside the warehouse hall. The route of the road is not fixed. This means that it can move freely to the place where the required items from the order are currently located. In addition, there are no specific rules with respect to which an employee should properly place elements on a pallet or from which elements should start picking. If a given product is pledged by another product, the employee has to move the unnecessary product to another place. After the goods are put away, they take the right product, which is on the picking list. The whole process is shown in Figure 7.

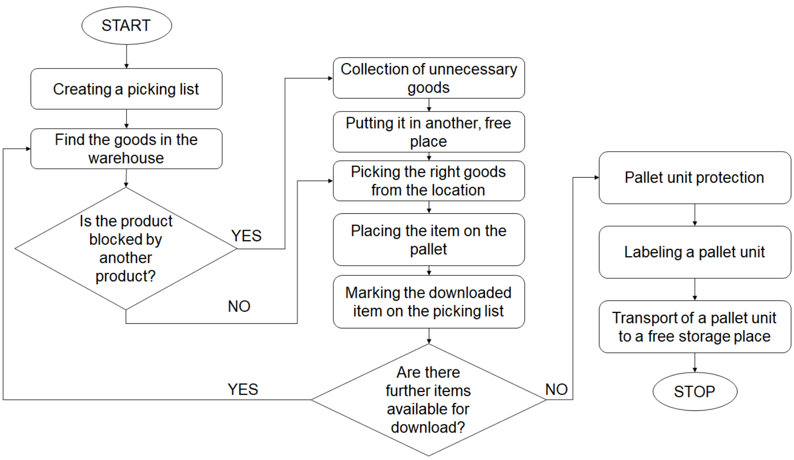

Figure 7. The picking process before the change

Source: Authors' own study.

According to Peterson and Aase (2017), picking is the most expensive activity in the warehousing process and may reach 55% of the total cost of warehouse operations. Therefore, it is an important element when analyzing productivity. One of the elements that affects picking is travel time, which can be wasteful. Therefore, guided by the study of Purba et al. (2018), the key to improving productivity is how to eliminate losses in the form of traffic by analyzing the warehouse layout.

In the company analysis of the picking process was performed on an identical order at two different time intervals for 40 sets of store shelves. The picking process has been divided into 4 operations: transport, stacking goods on a pallet, labeling, and securing. In the "transport" operation, time was measured for the following activities: searching for goods, activities related to the manipulation of goods that are not needed at the moment, transport.

The most labor-intensive part of this process is stacking them on a pallet, as shown in Figure 8, and a lot of time is also spent on finding the picking locations and transporting them. Transport takes an employee 27%, while the arrangement of individual elements on a pallet 56%.

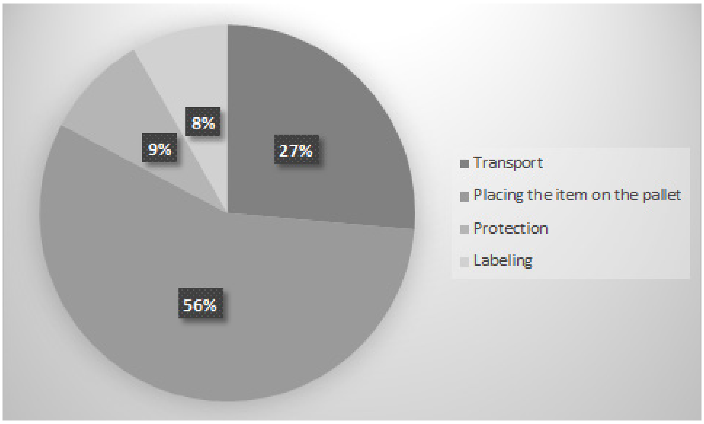

Figure 8. The share of individual times of operations performed during the picking process

Source: Authors' own study.

The activities securing the pallet unit with the load are accompanied by manual work without the use of specialized machines and tools. Due to the distribution of the assortment inside the warehouse based on the technique of free storage spaces, the total duration of the picking process and individual pallet units may differ from each other. This is mainly due to the fact that, depending on the rotation of individual assortment items, the place of their storage changes.

After designing the new layout of the warehouse and proposing the shelves, the activities related to searching for goods, putting away goods that are not needed at the moment, transporting, have been eliminated. The picking process itself has become simpler and the picking time has been shortened, as shown in Figure 9. The presented research clearly demonstrates the relationship between warehouse efficiency, process a warehouse and the warehouse's spatial layout and, thus, complements the research carried out by Buba et al. (2019).

The analyzed indicators before and after the improvement refer to the assessment of the warehouse and the effects of implementation of the first pillar of sustainable development, which is economic growth. Improving the quality of operations performed in the warehousing process results in cost reduction, better use of resources and improved system efficiency, which is also confirmed by the research of Beamon and Ware (1998).

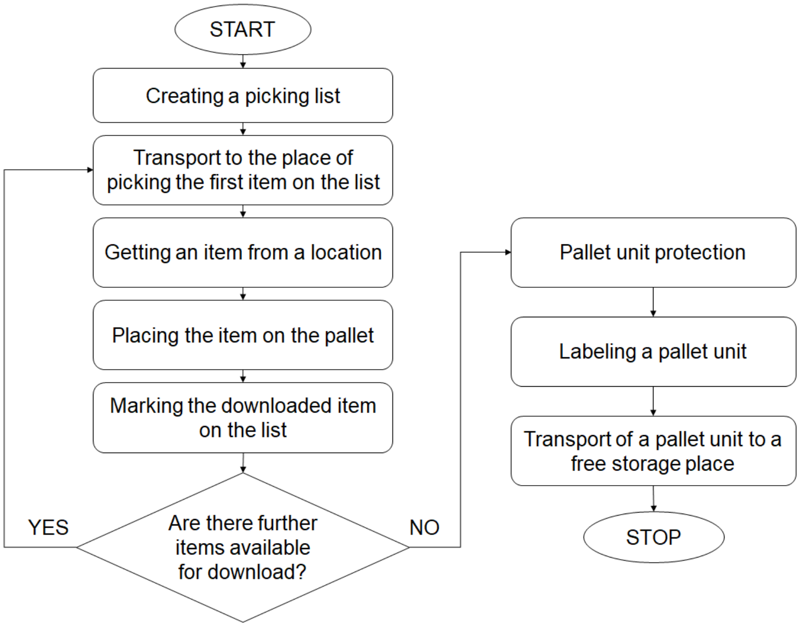

Figure 9. The picking process after the change

Source: Authors' own study.

An employee who completes does not have to search for goods in the warehouse anymore. The activities related to putting away goods that block the goods needed at the moment have also been eliminated. Eliminating unnecessary activities reduces the risk of damaging a given product.

The new layout with the racks has an impact on the duration of the picking process. In the old arrangement, where there are no shelves and there is block storage on the floor, the duration of 40 sets of store shelves was over 5 hours. On the other hand, in the new system, the picking process lasts over 3 hours, as shown in Figure 10.

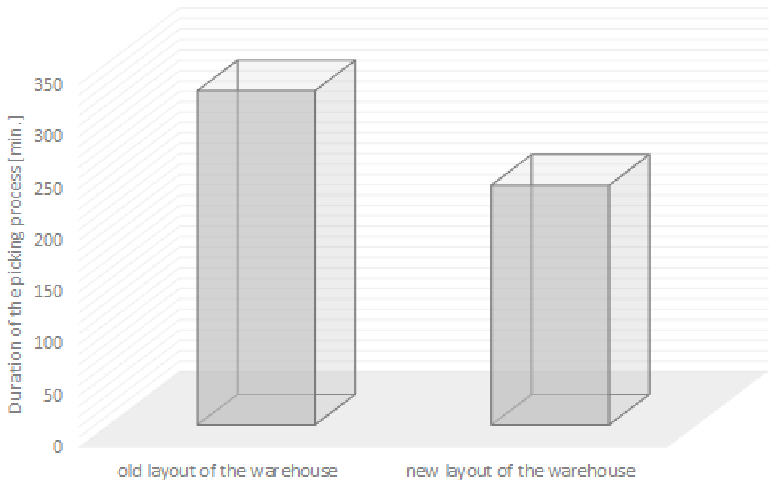

Figure 10. Duration of the picking process

Source: Authors' own study.

By proposing a new spatial layout for the warehouse and using the shelves, the company will increase the capacity of the warehouse. This will reduce handling movements and increase the level of work safety and the level of storage of goods.

During the picking process, the employee was forced to manipulate the goods multiple times, which causes an additional burden. The aspect of work safety is also important. Agreeing with the work of Tytyk and Mrugalska (2018), the desire to alleviate humankind of its toil was and is dictated by economic and humanitarian considerations (in that order). Before the changes were implemented, employees clearly indicated fatigue. However, after the implementation, through interviews, employees expressed satisfaction with the improvement of workplace safety conditions. They also pointed out issues related to ease of picking and inventorying, as well as a standardized warehouse process. Thus, these were steps in the methodology involving assessing the warehouse in terms of increasing social responsibility.

Unnecessary manipulation of goods, looking for goods in the storage area increases the consumption of resources available to the warehouse, especially means of transport. Such actions also have consequences in terms of environmental protection. The annual energy consumption for charging before the changes were implemented was 6,072.192 kWh/year, whereas after the implementation, it decreased to 3,048.192 kWh/year. Actions aimed at reducing consumption contribute to minimizing the negative impact on the natural environment, aligning with the goal in the methodology involving increasing environmental protection.

Also answering the research question posed in the methodology, design practices used to balance economic goals with the needs of employees and environmental protection are: ergonomics of the work space, optimization of the spatial layout, monitoring of resource consumption. Designing workstations and warehouse space with ergonomics in mind can improve the efficiency and comfort of employees, which translates into increased operational efficiency. Regularly monitoring your energy and other resource use can help you identify areas where you can save. This also leads to reduced operating costs and environmental impact.

Conclusions

Nowadays, the issue of proper planning of warehouse space is becoming more and more important. The strength of the company and its partners is the appropriate design of all elements of the storage process and efficient organization of the warehouse. That is why it is so important to act according to a specific methodology and not to omit any of the sustainable pillars.

By verifying the proposed methodology, the company increased the efficiency of the warehouse's current operation and improved environmental and social aspects. However, by using the previously mentioned warehouse space design practices, they can help achieve a balance between economic goals, employee needs and environmental protection. It should also be remembered that a properly designed spatial layout of the warehouse also affects the elements of logistic customer service.

Using a case study, the authors verified the presented design methodology and simultaneously identified economic, social and environmental benefits. The article may serve as an inspiration for further research on the sustainable design of spatial systems and encourage the use of innovative design practices to achieve a balance between economic, social and environmental goals.

Acknowledgments

This research was funded by grant of the Poznań University of Technology, project ID: 0812/SBAD/4202.

References

Ashayeri, J., Gelders, L.F., & Wassenhove, L. (1985). A microcomputer-based optimization model for the design of automated warehouse. *International Journal of Production Research*, *23*(4), 825–839.

Bank.pl (2024). *Inwestycje zdecydują o rynku powierzchni magazynowych w 2024 roku*. https://bank.pl/inwestycje-zdecyduja-o-rynku-powierzchni-magazynowych-w-2024-roku

Bassan, Y., Roll, Y., & Rosenblatt, M.J. (1980). Internal layout design of warehouse. *AIIE Transactions*, *12*(4), 317–322. **https://doi.org/10.1080/05695558008974523**

Beamon, B.M., & Ware, T.M. (1998). A process quality model for the analysis, improvement and control of supply chain systems. *Logistics Information Management*, *11*(2), 105–113.

Berry, J.R. (1968). Elements of warehouse layout. *International Journal of Production Research*, *7*(2), 105–121.

Buba, M.G., Das, D.P., Ghadai, S.K., & Bajpai, A. (2019) The effect of integrated warehouse operation efficiency on organizations performance. *International Journal of Recent Technology and Engineering*, *8*(2), 1664–1668. **https//doi.org/10.35940/ijrte.B2461.078219**

Caron, F., Marchet, G., & Perego, A. (2000). Optimal layout in low-level picker-to-part systems. *International Journal of Production Research*, *38*(1), 101–117.

De Koster, R., Le-Duc, T., & Roodbergen, K.J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, *182*(2), 481–501. **https://doi.org/10.1016/j.ejor.2006.07.009**

Golińska-Dawson, P., Werner-Lewandowska, K., & Kosacka-Olejnik, M. (2021). Responsible resource management in remanufacturing-framework for qualitative assessment in small and medium-sized enterprises. *Resources*, *10*(2), 19.

Gu, J., Goetschalckx, M., & McGinnis, L.F. (2007). Research on warehouse operation: A comprehensive review. *European Journal of Operational Research*, *177*(1), 1–21. **https://doi.org/10.1016/j.ejor.2006.02.025**

Gu, J., Goetschalckx, M., McGinnis, L.F. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research*, *203*(3), 539–549. **https://doi.org/10.1016/j.ejor.2009.07.031**

Huertas, J.I., Diaz, J., & Trigos, F. (2007). Layout evaluation on large capacity warehouses. *Facilities*, *25*(7/8), 259–270. **https://doi.org/10.1108/02632770710753307**

Kawęcki, R., & Gola, A. (2022). Pick performance systems as an it support for order completing – a case study. *Lecture Notes in Mechanical Engineering*, *275819*, 105–115.

Koliński, A., & Werner-Lewandowska, K. (2021). Determinants of the use of logistic labels by 3PL and 4PL operators – results of studies in Poland. *European Research Studies Journal*, *24*(2B), 871–881.

Kudelska, I., & Niedbał, R. (2020). Technological and organizational innovation in warehousing process – research over workload of staff and efficiency of picking stations. *E&M Economics and Management*, *23*(3), 67–81. **https://doi.org/10.15240/tul/001/2020-3-005**

Lee, H.L., Lee, M.H., & Hur, K.S. (2005). Optimal design of rack structure with modular cell in AS/RS. *International Journal of Production Economics*, *98*(2), 172–178. **https://doi.org/10.1016/j.ijpe.2004.05.018**

Lee, C.K.M., Lv, Y., Ng, K.K.H., Ho, W., & Choy, K.L. (2018). Design and application of Internet of Things-based warehouse management system for smart logistics. *International Journal of Production Research*, *56*(8), 2753–2768. **https://doi.org/10.1080/00207543.2017.1394592**

Lerher, T. (2006). Design and evaluation of the class-based multi-aisle AS/RS. *International Journal of Simulation Modeling*, *5*(1), 25–36. **https://doi.org/10.2507/IJSIMM05(1)3.048**

Lin, L.C., & Sharp, G.P. (1999). Quantitative and qualitative indices for the plant layout evaluation problem. *European Journal of Operational Research*, *116*(1), 100–117. **https://doi.org/10.1016/S0377-2217(98)00046-0**

Ma, L., & Mao, J. (2019). Research on layout optimization of cold chain warehouse center based on SLP method. In *The 3rd International Conference on Electronic Information Technology and Computer Engineering (EITCE)*. Xiamen, China (pp. 298–301). **https://doi.org/10.1109/EITCE47263.2019.9095257**

Marziali, M., Rossit, D.A., & Toncovich, A. (2021). Warehouse management problem and a KPI approach: A case study. *Management and Production Engineering Review*, *12*(3), 51–62. **https://doi.org/10.24425/mper.2021.138530**

Matson, J.O., & White, J.A. (1982). Operational research and material handling. *European Journal of Operational Research*, *11*(4), 309–318. **https://doi.org/10.1016/0377-2217(82)90196-5**

Mohamud, I.H., Kafi, Md.A., Shahron, S.A., Zainduddin, N., & Musa, S. (2023). The role of warehouse layout and operations in warehouse efficiency: A literature review. *Journal Européen des Systémes Automatisés*, *56*(1), 61–68. **https://doi.org/10.18280/jesa.560109**

Muharni, Y., Kulsum, & Khoirunnisa, M. (2019). Warehouse Layout Designing of Slab Using Dedicated Storage and Particle Swarm Optimization. *IOP Conference Series: Materials Science and Engineering*, *532*(1), 012003. **https://doi.org/10.1088/1757-899X/532/1/012003**

Önüt, S., Tuzkaya, U.R., & Doğaç, B. (2008). A particle swarm optimization algorithm for the multiple-level warehouse layout design problem. *Computers & Industrial Engineering*, *54*, 783–799.

Peterson, C.G., & Aase, G.R. (2017). Improving order picking efficiency with the use of cross aisles and storage policies. *Open Journal of Business and Management*, *5*, 95–104.

Polkowski, M., & Kotowski, M. (2020). Rynek magazynowy w Polsce. *JLL*.

Purba, H.H., Mukhlisin, Aisyah, S. (2018). Productivity improvement picking order by appropriate method, value stream mapping analysis, and storage design: A case study in automotive part center. *Management and Production Engineering Review*, *9*(1), 71–81. **https://doi.org/10.24425/119402**

Rahman, S. (2006). Quality management in logistics: An examination of industry practices. *Supply Chain Management: An International Journal*, *11*(3), 233–240. **https://doi.org/10.1108/13598540610662130**

Roodbergen, K.J., Sharp, G.P., & Vis, I.F.A. (2008). Designing the layout structure of manual order picking areas in warehouses. *IIE Transactions*, *40*(11), 1032–1045. **https://doi.org/10.1080/07408170802167639**

Roodbergen, K.J., & Vis, I.F.A. (2006). A model for warehouse layout. *IIE Transactions*, *38*(10), 799–811. **https://doi.org/10.1080/07408170500494566**

Shqair, M.I., & Altarazi, S.A. (2014). Layout design of multiple blocks class-based storage strategy warehouses. In *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management*. **https://doi.org/10.13140/2.1.2779.1047**

Sooksaksun, N., & Kachitvichyanukul, V. (2010). Particle swarm optimization for ware-house design problem. In *The 11th Asia Pacific Regional Meeting of International Foundation for Production Research*.

Tytyk, E., & Mrugalska, B. (2018). Towards innovation and development in ergonomic design: Insights from a literature review. *Procedia – Social and Behavioral Sciences*, *238*, 167–176. **https://doi.org/10.1016/j.sbspro.2018.03.020**

Van den Berg, J.P. (1999). A literature survey on planning and control of warehousing systems. *IIE Transactions*, *31*(8), 751–762.

Žunić, E., Beširević, A., Delalić, S., Hodžić, K., & Hasić, H. (2018). A generic approach for order picking optimization process in different warehouse layouts. In *The 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)* (pp. 1000–1005). **https://doi.org/10.23919/MIPRO.2018.8400183**