frontiers | Frontiers in Built Environment

TYPE Original Research
PUBLISHED 03 February 2025
DOI 10.3389/fbuil.2025.1455166

OPEN ACCESS

EDITED BY
Assed N.Haddad,
Federal University of Rio de Janeiro, Brazil

REVIEWED BY
Zienab F.R.Ahmed,
United Arab Emirates University, United Arab Emirates
Saija Toivonen,
Aalto University, Finland

*CORRESPONDENCE
Hanna Bonekämper,
hanna.bonekaemper@kit.edu

RECEIVED 01 July 2024
ACCEPTED 13 January 2025
PUBLISHED 03 February 2025

CITATION
Bonekämper H (2025) Adaptive reuse for sustainable urban development: vertical farming in former department stores. German case study.
Front. Built Environ. 11:1455166.
doi: 10.3389/fbuil.2025.1455166

Adaptive reuse for sustainable urban development: vertical farming in former department stores. German case study

Hanna Bonekämper[1,2]*

[1]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, [2]Institute for Technology and Management in Construction, Faculty of Civil Engineering, Geo and Environmental Sciences, Karlsruhe Institute of Technology (KIT), Karlsruhe, Baden-Württemberg, Germany

Since digitalization has changed people's shopping behavior, department stores have partly become obsolete. Concepts for adaptive reuse can help avoid future vacancies or counteract existing ones. However, developing viable concepts for reuse is challenging due to the layout of department stores, particularly regarding building depth, which limits natural light penetration throughout the structure. While vertical farming as a technology is not new, its integration into former department stores is. The unique contribution of this work lies in offering new perspectives on repurposing the growing number of vacant retail spaces. Through an architectural case study, this research explores how vertical farming could be implemented in such buildings. Using a department store in Wuppertal, Germany, as an example, the proposed solution is tailored to the site's structural conditions. Methods from the field of architecture were applied, including a site analysis followed by an iterative design process that progressed from conceptual planning to detailed development. The results include floor plans, elevations, sections, and visualizations. The proposed design indicates that these buildings are well-suited for vertical farming, offering significant added value to the city. This contribution provides an interdisciplinary concept that uncovers further research questions.

KEYWORDS

adaptive reuse, vacant building, department stores, vertical farming, sustainable urban development (SUD), mixed-use urban development, urban studies

1 Introduction

This work aims to answer the question of whether vertical farming can serve as a viable adaptive reuse concept for former department stores. It is explored primarily within the context of a case study in Wuppertal, Germany. To address this, this chapter begins with an overview of the transformation within the retail sector, highlighting the changing demand and the significant potential to repurpose vacant retail spaces in a meaningful way.

Department stores have partly become obsolete due to the increasing digitalization, which has made online shopping possible and changed people's shopping behaviour (Regio Data Research, 2024). The COVID-19 pandemic accelerated this process, as department stores were closed during often long lockdowns (Zhang, 2023). Friedrich (2020) observes that during the lockdown in Hamburg, Germany, the city centre lost its original purpose and appeared deserted. The usual consumption buzz that is typically present in the city centre was absent (Friedrich, 2020).

Partly as a consequence of the change in shopping behaviour, the number of German department stores has decreased significantly in recent years. In 2004, there were 290 department stores, whereas in 2019, the number had declined to 175 (Statista, 2024). Galeria Karstadt Kaufhof is one of the largest operators of department stores in Germany. In 2020, the total count stood at 171 branches, however, by 2021/2022, this figure had fallen to 131 (Statista, 2024). In 2023, the closure of further 47 Galeria Karstadt Kaufhof branches was announced (Handelsblatt, 2023). Researchers from the project "Obsolete Stadt" expect the trend of closure to continue: They expect an additional 13 percent of department stores to close in Germany until 2030 (Obsolete Stadt, 2020).

Vacant buildings, such as department stores, can negatively affect the city centre such as through impairments in appearance and negative image effects (Hangebruch and Othengrafen, 2022). This can impact surrounding businesses, and thereby the local economy. If the buildings are not only vacant but also in disrepair, this may lead to heightened crime in the neighbourhood - the concept of the "broken windows theory" postulates that decaying infrastructures invites criminal actions (Dempsey et al., 2009).

When buildings become obsolete, two options arise: Firstly, the buildings could undergo demolition, and the materials could be used for a new construction project. The extraction of materials from buildings, infrastructure, vehicles, and other durable goods is known under the term "urban mining". Secondly, there is the option of converting the building and making it available for a new use. This idea is encapsulated by the term "adaptive reuse", which involves revitalizing buildings in a sustainable manner or altering the purpose of an existing structure (Douglas, 2006). The term "adaptive" is derived from the Latin words "ad" (to) and "aptare" (fit), emphasizing the idea of aligning the structure with a new or renewed purpose (Douglas, 2006).

Given the historical value of certain department stores, prioritizing adaptive reuse over demolition is recommended (Aigwi et al., 2018). This perspective aligns with Hangebruch and Othengrafen's (2022) emphasis on not only the environmental benefits but also the cultural importance of reusing department stores, fostering a connection between individuals and their familiar surroundings. Such considerations can be associated with the concept of social sustainability. However, the decision of adaptive reuse must be made in the context of holistic sustainability (economic, ecological, social) determining the extent to which adaptive reuse is viable or not. There is a growing perception that the adaptive reuse of existing buildings, especially those under heritage protection, may not be economically viable. Conservation requirements can potentially elevate construction costs, while the ongoing maintenance expenses for an old building, even after refurbishment, typically remain higher than those for a new construction (Douglas, 2006). Contrary perspectives posit that the repurposing of a building is more cost-effective than the demolition and reconstruction of a structure (Aigwi et al., 2018).

2 Materials and methods

This study aims to answer the following research question:

> *Does vertical farming represent a viable adaptive reuse concept for former department stores, particularly within the context of Wuppertal, Germany?*

The scholarly discourse has not yet explored the adaptive reuse of department stores through vertical farming. Currently, no projects exist that implement vertical farming within department stores. This investigation serves as a theoretical case study in the field of architecture, framed as a case-based solution. It aims to assess the feasibility of integrating vertical farming into department stores, focusing on the design possibilities such integration entails.

The architectural case study presented here serves as a first step toward further research in this area. The additional research raised by this work are further elaborated in the further research section below.

The development of the architectural case study involved the following steps, as shown in Figure 1.

- 1. Selection of the building category department store: Prompted by reports from 2020 indicating the closure of numerous department stores, largely due to insolvency. This building category was chosen to explore how vacancy resulting from these closures can be prevented and which alternative uses might be suitable to mitigate empty spaces.
- 2. Selection of vertical farming as a new use: This choice was driven by the fact that vertical farming represented a novel approach to building usage at the time, making it an intriguing subject for exploration, particularly in an urban context.
  - 2.1 Analysis of vertical farming through literature review: This aimed to enhance the understanding of vertical farming as a technology. The focus was not on determining the building requirements essential for vertical farming. Instead, these criteria were developed and applied in the case study-based iterative process to adapt the technology to existing structures, which is further elaborated upon later.
- 3. Selection of the case study in Wuppertal, Germany: Chosen due to spatial proximity to the author, this selection facilitated on-site visits and analyses. The department store was not vacant at the time of the study, and there were no specific discussions regarding the closure of the branch. However, given the general situation of department stores in Germany, it was foreseeable that this department store would eventually be affected by vacancy, as has been the case since January 2024. Additionally, it was important that this building is partially under monument protection. This allows for an examination of the tension between innovative uses and the preservation of historical, protected structures, as the department store in Wuppertal is indeed partially listed as a historical monument.
  - 3.1 Analysis: The initial phase involved an online investigation of the building, utilizing resources such as Google Images for a visual representation of the site, as well as Google Maps and tim-online. nrw.de to gather detailed geographical and urban planning information. While architectural information, such as floor plans, sections, and elevations for public or well-known buildings, can often be found online, this was not the case for the building in question. This lack of comprehensive information

necessitated further on-site analyses to establish a clearer understanding of the building's potential for adaptation.

- 3.2 Building Assessment: Given the limited availability of building data, additional documents were sought in the archives of the city of Wuppertal, accompanied by an on-site inventory. This process involved photogrammetry of the facades and measurements within the building. On-site, evacuation plans were observed, which must always be available for publicly accessible buildings in Germany. These evacuation plans were photographed and subsequently redrawn using CAD software, specifically ArchiCAD, to create a 3D model in conjunction with the photogrammetry. From this 3D model, floor plans, sections, and elevations of the building were generated, providing an initial planning basis. Throughout this entire process, no building data was made available by Galeria Kaufhof Karstadt.

- 4. Design Phase: The optimal design for utilization emerged through an iterative process. Initially, sketches were employed to create a spatial concept for the new usage (4.1.). Advancing in the project timeline, detailed designs were developed using CAD software (4.2.). The architectural concept was developed mostly in the floor plans, and the 3D model was repeatedly assessed for visual perception and optimal usability for vertical farming (4.3.). Architecture researchers and experts in vertical farming accompanied the process and provided support through their specialized knowledge. The output encompassed floor plans, sections, and elevations, accompanied by illustrative representations to enhance conceptual comprehension.
- 5. Presentation Phase: In this phase, all collected data and representations were compiled and communicated as a cohesive concept. This included preparing presentations and visual displays to effectively convey the design intentions and findings to stakeholders, ensuring a clear understanding of the proposed solution.

3 Department stores

3.1 Historical development

The origin story of department stores is closely related to the development of trade. This started in Stone and Bronze Age (Fischer, 2012), evolved over the traveling merchant to the market hall or the Bazaar, where the many small and mostly covered shops formed passages. Around 1852, hundreds of covered individual shops grew in Paris as "one oriental style bazaar role model together" (Okroy, 2015). The basis for this were "magasins de newautés", translated as "novelties businesses". One of those shops, today's Le Bon Marché in Paris, expanded to a "grand magasin", a department store. Le Bon Marché is considered the oldest of its kind and the cradle of department stores.

Galeria Karstadt Kaufhof traces its origins to the Jewish merchant Leonhard Tietz, who established the department store in 1879 under the name "Kaufhaus Tietz". Following the ascent of the Nazis in 1933, the company was seized as part of the "Aryanization" process and was subsequently renamed "Westdeutsche Kaufhof AG" (Okroy, 2015). During the 1960s, a notable surge was observed in the German department store industry. Remarkably, the market share of these establishments experienced a substantial increase, reaching up to 15 percent, particularly during the post-war Wirtschaftswunder (Wirtschaftswoche, 2024) spanning from 1949 to 1966 (Bmwk, 2024). In the 1980s, the decline for Galeria Kaufhof commenced as public interest in the "all under one roof" department stores waned (Wirtschaftswoche, 2024). In 2018, the merger of Galeria Kaufhof and Karstadt was announced (Bundekartellamt, 2018). In March 2020, Galeria Karstadt Kaufhof applied for government assistance to mitigate the economic consequences of the COVID-19 crisis.

3.2 Present situation

In 2023, the closure of 47 Galeria Karstadt Kaufhof branches was announced (Handelsblatt, 2023). By October of the same year, the predicament deepened for Signa, the owner of Galeria Karstadt Kaufhof. The group, established by René Benko, confronted significant challenges, particularly amidst the escalation of interest rates and the decline in real estate values. In November 2023, despite attempts to secure stability through a leadership change and external consultations, Signa's holding company initiated a self-administered insolvency procedure (Wirtschaftswoche, 2024). On 9 January 2024, Galeria Karstadt Kaufhof filed for insolvency once again (Wirtschaftswoche, 2024).

3.3 Adaptive reuse of department stores

With these challenges in the department store industry often leading to vacancies, it is important to develop solutions to maintain the attractiveness of city centres. Adaptive reuse of existing structures can shape identity and play a role in conserving architectural heritage, especially as large department stores serve as key points of identification for both residents and visitors (Hangebruch and Othengrafen, 2022). Between 1994 and 2019, seven out of ten vacant department stores underwent conversion or core renovation, while the remaining were demolished (Hangebruch and Othengrafen, 2022). According to Hangebruch and Othengrafen (2022), adaptive reuse of vacant department stores in Germany has undergone four main phases:

- 1990s and 2000s: Focus on fashion, technology, and hypermarket departments.
- 2000s and 2010s: Characterized by surge of inner-city shopping centres.
- Early 2010s: Restructuring into independent shop by dividing the space vertically.
- mid-2010s: Mixed-use concepts with reduced retail space.

This prompts an inquiry into the appropriateness of current adaptive reuse concepts in addressing contemporary challenges. The range of potential uses is vast, including residential, hotels, nursing homes, educational and cultural facilities, day-care centers, among others, which have already been successfully realized (Hangebruch and Othengrafen, 2022). Other exemplary ideas that have already been implemented for empty department stores include

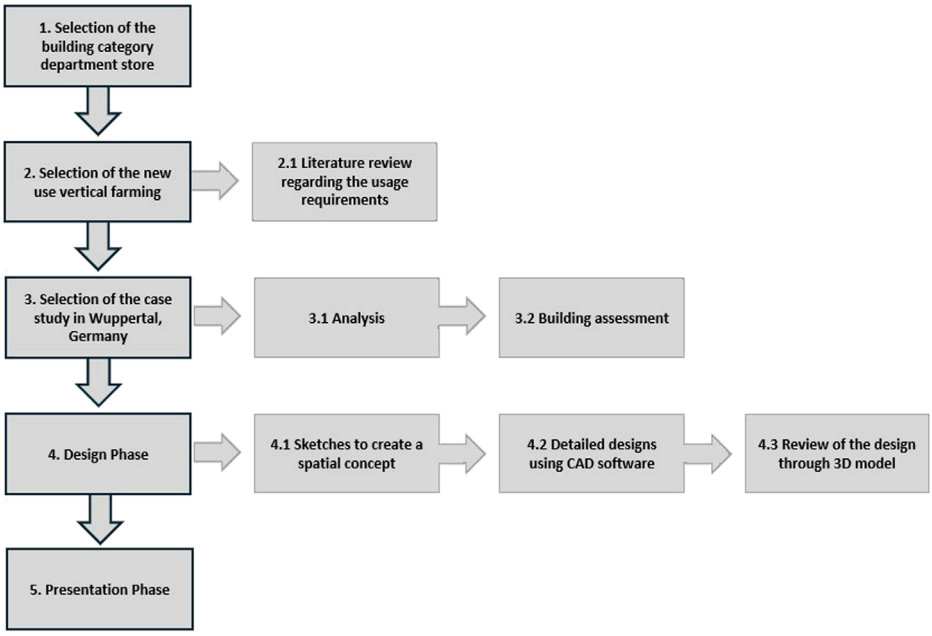

FIGURE 1
Flowchart illustrating the case study process.

kindergartens, climbing halls, art galleries, lecture halls or artificial surf waves (WDR, 2023). According to Heynkes (2019), repurposing department stores into spaces such as residences or offices, however, would be overly complex due to the layout of a typical department store - including the enormous depth of the buildings, which impedes the provision of sufficient natural lighting. Addressing this challenge would necessitate solutions such as integrating light wells into the existing structure. These efforts may involve complex renovation procedures or may not be structurally possible at all. However, Heynkes (2019) suggests that the conversion of former department stores holds potential for future food production. This, to the best of our knowledge, is the only source that explores vertical farming as a potential concept in former department stores, despite the fact that this offers numerous advantages and addresses current challenges.

4 New food concepts

The world's population is projected to reach 9.7 billion by the year 2050 (United Nations Department of Economic and Social Affairs, 2022). This represents an increase of approximately 1.62 billion individuals compared to the current population, which stands at approximately 8.08 billion (Deutsche Stiftung Weltbevölkerung, 2024). This highlights the need to feed an even larger population in the future. To address the already existing challenge of not being able to provide enough food for everyone in the world, Goal 2 of the Sustainable Development Goals (SDGs) aims to achieve a world without hunger by the year 2030 (United Nations, 2024). The projected increase in the future population and the fight against hunger among the world population necessitates additional resources, including expanded agricultural space to meet the growing demand for food.

However, approximately 80 percent of the accessible mainland is already required for the world's food production (Despommier, 2010). At the same time, land previously used for agriculture is increasingly dedicated to alternative purposes such as urbanization, infrastructure development, bioenergy production or the preservation of biodiversity (Lotze-Campen et al., 2008). Becoming an increasingly scarce resource, land is characterized by limited availability (Mishra et al., 2021). There is therefore a requirement for efficient and space-saving agricultural concepts.

4.1 Vertical farming

One space-saving agricultural concept is vertical farming. As vertical farming technology is not the focus of this work, only the basic functions are briefly explained. Heynkes (2019) describes vertical farms as "stacked levels in buildings or greenhouses, who have fruit all year round, vegetables, edible mushrooms, lettuce or algae".

The core of every vertical farm is the individual growth module. These are usually shaped as high racks, pillars or wall-like panels. In these modules, the plants can grow under controlled conditions in water instead of in soil (Zhuang et al., 2022). The plants receive nutrients via an individual adapted and controlled nutrient solution and are irradiated with LED lights (Coyle and Ellison, 2017). A wide range of fruits and vegetables are suitable for vertical farming: Berries, leafy vegetables, spinach, and some crucifers (Mishra et al., 2021), leafy greens such as lettuce and kale; aromatic herbs such as basil, parsley, thyme, cilantro; strawberries, tomatoes, microgreens, mushrooms, and root vegetables such as

carrots, beets, and radishes (Gageanu et al., 2023). Asseng et al. (2020) are investigating the potential of wheat cultivation in vertical farms. Yields would surpass the current global average annual wheat yield of 3.2 t/ha by a factor of 220–600. Bafort et al. (2022) are researching the agro-economic feasibility of growing the medicinal plant *Euphorbia peplus* (garden spurge) in vertical farming shipping containers. Especially for products intended for consumption, it should be noted that obtaining organic certification in Europe is unattainable since the certification process necessitates plants to grow in soil. Exemptions are granted for plants that naturally grow in water (DLG, 2023).

Vertical farming is usually realized in large warehouses (Aerofarms, 2020) or shipping containers (Freight Farms, 2020). Depending on the form chosen, these follow different business models. Aerofarms provides lettuce for sale. Freight Farms sells freight containers equipped with vertical farming technology. Additionally, there are in-store farms, exemplified by vertical farms within the retail grocery sector (DLG, 2023) such as the Start-up Infarm (Rnd, 2021).

4.2 Vertical farming: advantages and disadvantages

Vertical farming has both advantages and disadvantages in comparison to traditional agriculture. Firstly, it requires up to 10 times less water (nps, 2018). This efficiency is primarily attributed to the closed-loop circulatory system. Another advantage is a reduction in pesticide usage: Vertical farming can, since it is usually located in closed systems, offer enhanced pest control, leading to a reduction in pesticide usage and the preservation of agricultural product quality (Tooy et al., 2023). One disadvantage of vertical farming technology is the high energy requirement of the LED lights. This could lead to further pollution and greenhouse gas emissions. Additionally, the expenses for acquiring the LED lights used in vertical farming are prohibitive for many small-scale farmers (Coyle and Ellison, 2017). The primary advantage of vertical farming is the yield potential: Vertical farms can achieve significantly higher yields per unit of land compared to conventional agriculture by stacking multiple levels of plants (Coyle and Ellison, 2017). To calculate the yield of vertical farming, several variables must be considered. These include, above all, the product, i.e., which crop is to be produced, as well as the chosen vertical farming type (shipping container or warehouse).

The dimensions of a vertical farming shipping container are 40*8*9.5 ft (Freight Farms, 2024) which is 320 ft^2 or approximately 29.7 m^2. According to Freight Farms, the equivalent land yield of their vertical farming shipping container is 2–4 acres annually and the annual crop output is 2–6 tons (Freight Farms, 2024). Based on an average of 4 tons, this results in a daily yield of 10.96 kg or 0.37 kg/m^2. Zhuang et al. (2022) assume an annually yield of 115 kg/m^2 for lettuce and 20 kg/m^2 for strawberries. Calculated per day, this means 0.315 kg/m^2 for lettuce and 0.055 kg/m^2 for strawberries. Coyle and Ellison (2017) compare the yield of lettuce products within the field, greenhouse, and vertical farm technologies: 50,000 heads of lettuce/acre/year in field farming; 1,600,000 heads of lettuce/acre/year in greenhouses and 5,000,000 heads of lettuce/acre/year in a vertical farm. Based on a median weight for lettuce of 520 g (Prüße et al., 2001), this results in daily yield of 0.07 kg/m^2 for field farming; 2.28 kg/m^2 for greenhouse farming and 7.12 kg/m^2 for vertical farming.

Beyond that, vertical farming permits the cultivation of seasonal or regional crops year-round, in contrast to conventional farming, which is constrained by geographical and seasonal variations in yield (Sharma and Bakshi, 2022).

4.3 Vertical farming in cities

Furthermore, vertical farming holds a key advantage by closeness to the end consumer (rnd, 2020). Particularly in highly urbanized areas and urban "food deserts", vertical farms could emerge as an effective means to augment produce accessibility. This may bolster community food security (Specht et al., 2014) and reduce reliance on food imports. The city-state of Singapore currently has to import 90 percent of its food supply. Through the implementation of farms on rooftops, walls, and within warehouses, the country aims to domestically produce at least 30 percent of its consumption by 2030 (National Geographic, 2022). Despommier (2010) proposes the integration of vertical farming in cities and highlights that vertical farming eliminates the need for extensive transportation, thereby conserving fossil fuels. Sharma and Bakshi (2022) emphasize that there are inexpensive shipping containers or vacant warehouses that would be suitable for vertical farming even near the city. This would make it possible for metropolitan areas to receive fresh food while at the same time giving new life to unused infrastructure (Sharma and Bakshi, 2022).

5 The case study

Constructed in 1912, the department store in Wuppertal's city centre has undergone significant transformation over time. Heavily damaged in World War II, and partially dismantled and reconstructed in 1960, the result has been a distinctive blend of contrasting architectural periods. All over Germany, the blue-green facades from the 1960s became the trademark of Galeria Kaufhof Karstadt (Heimbüchel, 2001), some of which are now under monument protection. The building's substantial depth of 42 m limits natural daylight penetration. Operated by Galeria Karstadt Kaufhof until the end of 2023, the building has been vacant since January 2024. The city administration of Wuppertal is therefore actively seeking a new use for the property, with an emphasis on preventing prolonged periods of vacancy (Westfälischer Anzeiger, 2023).

6 Results: the case-based solution

6.1 The suggested concept

The concept aims to contribute to the revitalization of the city centre by injecting new life and enhancing its overall attractiveness. This is depicted in Figures 2–8, which graphically represent the building as a new focal point in the city.

The proposed utilization of vertical farming in the former department store is apt for several reasons:

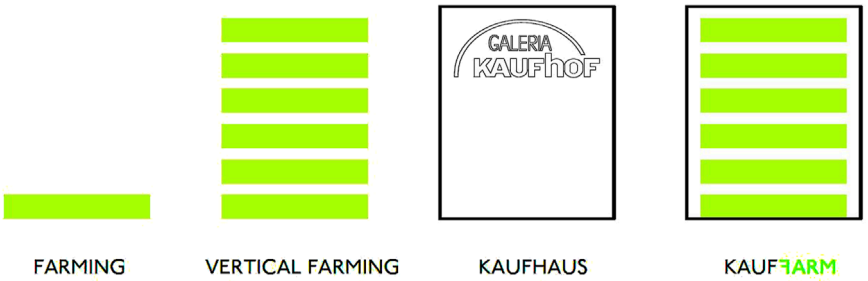

FIGURE 2
Adaptive reuse concept: Implementing vertical farming in former department stores.

FIGURE 3
Conceptual section illustrating the various uses of the building.

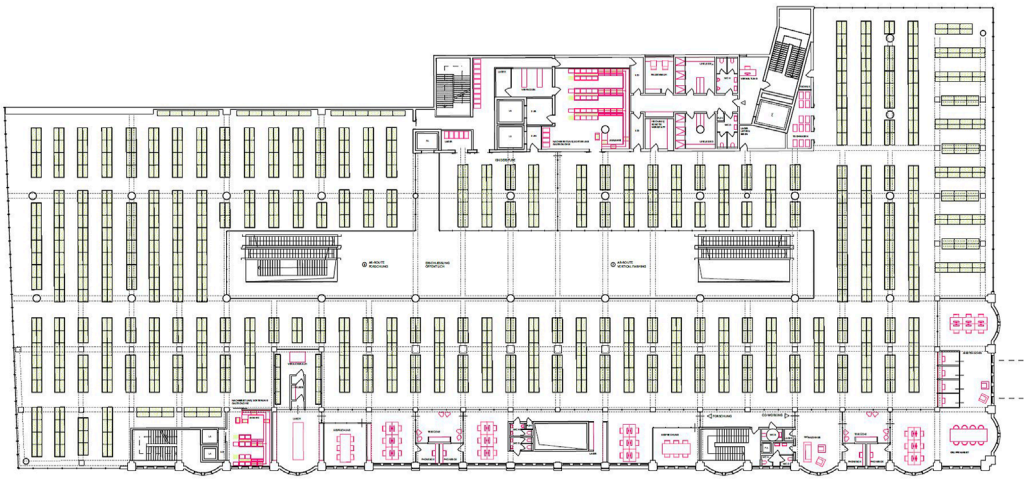

FIGURE 4
Floor plan of the vertical farming level.

FIGURE 5
Section view of the building based on the created photogrammetry.

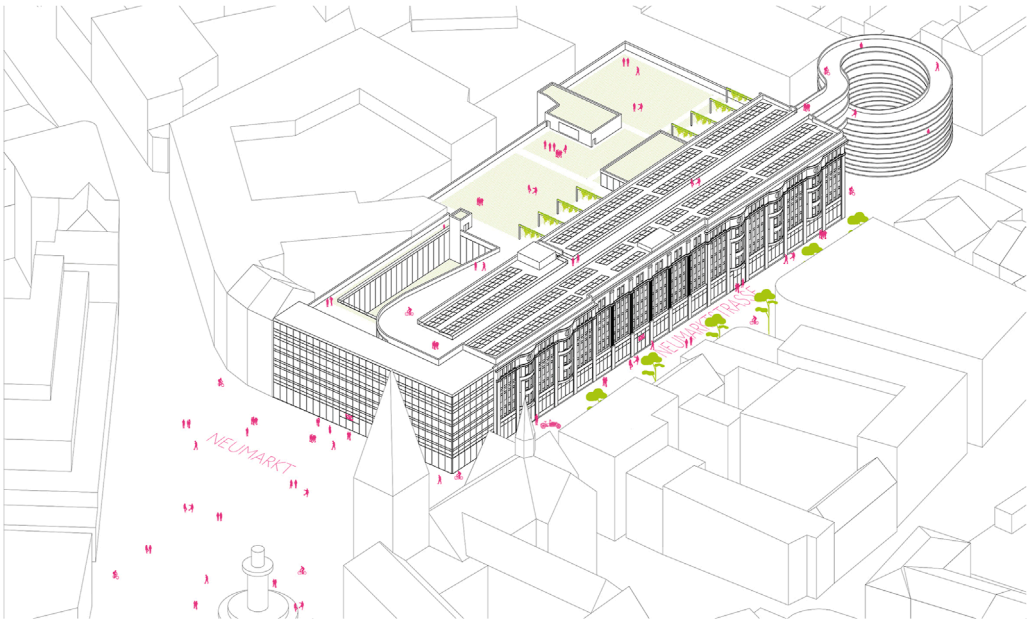

FIGURE 6
Conceptual illustration of the converted department store.

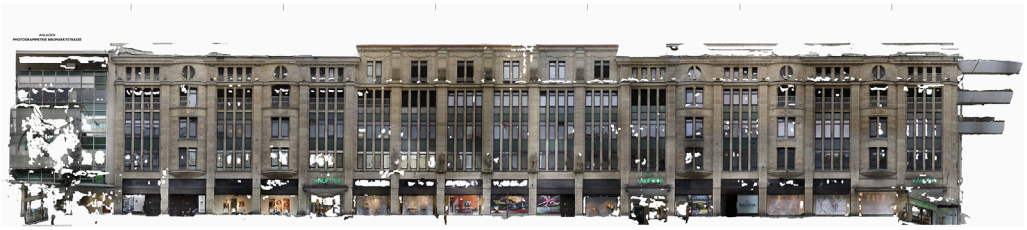

FIGURE 7
Photogrammetry of one of the Buildings facade.

FIGURE 8
Perspective/3d view of the vertical farming level.

- Central Location: Inner-city areas are often in high demand due to limited availability. These prime locations, although frequently occupied, hold significant value. The unique advantage lies in the capacity to cultivate products directly where people live, showcasing the potential for efficient food production in urban centres.
- Artificial Lighting in Vertical Farming: The artificial lighting negates the relevance of concerns associated with the depth of the building.
- Limited Feasibility of Other Uses: Alternative uses would require significant construction efforts to be viable.

In addition to the vertical farm itself, the department store would house a market hall and a workshop that serves as an incubator for emerging technologies on the ground floor. The products cultivated within the vertical farm constitute an integral component of the value chain, primarily retailed in the market hall. Furthermore, the proposed reuse accommodates versatile uses, including coworking spaces and research facilities. The rooftop garden is envisioned as a vibrant space accessible to visitors. Featuring expanses of lawns, a summer cinema, and gastronomic facilities, it is designed to provide an inviting environment for extended stays. The synergy derived from the integration of production, new employment opportunities, retail, educational landscapes, and gastronomy contributes to the transformation of Wuppertal into a vibrant city. By evolving from locus of consumption, the building transcends its traditional role and emerges as a multifaceted third place for the community.

The spatial distribution of vacant department store branches across Germany presents a unique opportunity to establish replicable concepts. This approach allows for the implementation of innovative projects on a broader scale, leveraging the distinct characteristics of each location. By strategically transforming each vacant department store into a vertical farm as a multifunctional hub, a comprehensive blueprint arises.

6.2 Minimally invasive adaptive reuse

Minimally invasive adaptive reuse emphasizes sensible handling of existing building structure in the context of historically significant or architecturally valuable structures. This concept entails implementing only those measures essential for the intended reuse. This approach necessitates a paradigm shift among planners, architects, and other stakeholders. Jager (2020) underscores that the essence of adaptive reuse culture lies in reimagining an existing structure. He illustrates this concept with a historical anecdote involving Michelangelo, who, tasked with building a church, recognized that a bathing temple already possessed the spatial requisites for a church.

In the case of the vertical farm in the former department store, the minimally invasive adaptive reuse is achieved by considering the following points:

- The integration of the new vertical farm use aligns structurally with the existing department store building, minimizing the structural effort required for conversion. Technical facilities such as the existing infrastructure, including freight elevators, and logistical components like loading areas can be repurposed as they are integral to the operation of the vertical farm.
- Certain elements of the building structure, such as the access ramp of the parking deck, become redundant in the new context. However, instead of opting for an extensive demolition process, emphasis is placed on exploring alternative uses for these structures. For instance, the existing ramp can be repurposed for public use as a sports ramp.
- New understanding of aesthetics: Surfaces need not conform to contemporary trends; rather, their original character can contribute to a sustainable approach to material utilization. This approach advocates for implementing only the necessary measures essential for operation while preserving the historical essence of the structure.

6.3 Further research

The adaptive reuse of department stores for vertical farming presents numerous advantages, with a particular emphasis on its potential for contributing to urban revitalization. However, several aspects necessitate critical discussions and further exploration.

Firstly, an investigation into the adaptability of the current technical building infrastructure in department stores for the integration of vertical farming practices is crucial. A structural integrity study is necessary to evaluate whether the existing structure can adequately support the requirements of vertical farming facilities.

Secondly, comprehensive research needs to address legal and regulatory considerations, incorporating a thorough examination of factors such as zoning regulations, land-use plans and fire safety measures.

Thirdly, economic evaluation must address questions about whole life cycle costs. This should also examine the urban impacts, examine potential increases in the city's attractiveness and methods for quantifying such improvements. Suitable business models must be found that make the use of vertical farming in inner-city areas economically sustainable. Suitable business models must be found that make the use of vertical farming in inner-city areas economically sustainable. These business models should also incorporate a diverse range of products to mitigate the risk of market saturation, particularly concerning leafy greens.

Finally, a detailed examination of challenges such as energy consumption is essential. The actual sustainability of vertical farming is a subject of ongoing research, emphasizing the importance of scrutinizing its environmental impact, resource efficiency and the need for conducting life cycle assessments.

It is crucial, however, to also recognize the imperative for novel and efficient technologies to address the increasing demand for food.

7 Discussion

This work has aimed to formulate an adaptive reuse concept for a department store, specifically exploring the feasibility of vertical

farming as a use for vacant retail spaces. The case study in Wuppertal, Germany, served as an illustrative example.

A comparison with existing literature on this specific concept was not possible due to the lack of studies addressing it. Therefore, this work can be seen as a first conceptual approach, and further research, as mentioned in the "Future Research" section, is urgently needed to continue assessing the feasibility of the concept and to evaluate its transferability to different geographical contexts. It is crucial to recognize that this work predominantly focuses on a German case study, which may limit its generalizability to other regions. Local legal frameworks must be thoroughly examined, as regulations differ significantly across regions. Furthermore, the suitability of buildings for this concept may also differ; for example, while department stores are common in some regions, other types of buildings may be more appropriate in different countries. Future research should explore these regional variations to better understand the adaptability and potential of the concept in diverse contexts.

The concept has been presented to a diverse group of experts, including professionals from the real estate industry, agricultural specialists, and urban decision-makers, in order to gather valuable feedback and insights. While this feedback provides a strong foundation, the question of whether this process constitutes sufficient validation remains open for further discussion. Given that the concept is theoretical in nature, its practical implementation is considered the best method for validating the model. However, due to its innovative nature and the considerable financial risks involved, additional research is necessary before it can be considered for real-world application. Nevertheless, despite the theoretical nature of the concept, several insights have been gained throughout the process, which can serve as a valuable foundation for future research and practical exploration:

One notable advantage is the potential to repurpose vacant areas, thereby preventing a loss of attractiveness in German city centres. This repurposing can revitalize neighborhoods, drawing in visitors and enhancing local economies. The central location of department stores facilitates the cultivation of products directly where people live, promoting food accessibility and reducing transportation emissions.

Moreover, the structural characteristics of department stores are well-suited for vertical farming. The existing infrastructure, including freight elevators and logistical components such as loading areas, can be effectively repurposed to support farming operations. This compatibility not only reduces the need for extensive renovations but also allows for a more efficient use of resources.

Furthermore, vertical farming, particularly when integrated with various uses as a diverse mixed-use structure, significantly contributes to the livability of city centres. By incorporating agricultural elements into urban settings, this approach creates a more pleasant environment for city residents, enhancing their overall quality of life, particularly through complementary uses such as gastronomy, coworking spaces, and market halls.

In summary, the adaptive reuse of department stores for vertical farming presents a promising solution for revitalizing vacant retail spaces. This underscores the primary advantages of such a transformation in preventing vacancies and enhancing quality of life in cities, while also acknowledging that there can be ecological benefits associated with this approach. A key implication of the findings is that vacant retail spaces could be repurposed for new uses, potentially alleviating the issue of urban vacancy. This shift could reduce the demand for traditional retail spaces, leading to changes in the urban landscape and altering the dynamics of local economies. However, such a transition may also disrupt existing business models, with some industries potentially facing decline. Additionally, there are financial risks involved, as the implementation of such a concept could require substantial investment without guaranteeing demand or success. Therefore, it is crucial to carefully evaluate the potential market reception and the economic feasibility before proceeding with practical applications of this concept.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HB: Writing–original draft.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The author acknowledges the use of ChatGPT (OpenAI, GPT-4) as a supportive tool for translating and summarizing content. Its assistance was particularly valuable as the author is not a native English speaker.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aerofarms (2020). Aerofarms to build world's largest r&d indoor vertical farm. Available at: https://www.aerofarms.com/aerofarms-to-build-worlds-largest-rd-farm/ (Accessed February 27, 2024).

Aigwi, I. E., Egbelakin, T., and Ingham, J. (2018). Efficacy of adaptive reuse for the redevelopment of underutilised historical buildings: towards the regeneration of New Zealand's provincial town centres. *Int. J. Build. Pathology Adapt.* 36 (4), 385–407. doi:10.1108/IJBPA-01-2018-0007

Asseng, S., Guarin, J. R., Raman, M., Monje, O., Kiss, G., Despommier, D. D., et al. (2020). Wheat yield potential in controlled-environment vertical farms. *Proc. Natl. Acad. Sci.* 117 (32), 19131–19135. doi:10.1073/pnas.2002655117

Bafort, F., Kohnen, S., Maron, E., Bouhadada, A., Ancion, N., Crutzen, N., et al. (2022). The agro-economic feasibility of growing the medicinal plant *Euphorbia peplus* in a modified vertical hydroponic shipping container. *Horticulturae* 8, 256. doi:10.3390/horticulturae8030256

Bmwk (2024). Wirtschaftswunder soziale marktwirtschaft (1949-1966). Available at: https://www.bmwk.de/Redaktion/DE/Artikel/Ministerium/49-66.html (Accessed February 27, 2024).

Bundeskartellamt (2018). Zusammenschluss von Karstadt und Kaufhof. Available at: https://www.bundeskartellamt.de/SharedDocs/Meldung/DE/Pressemitteilungen/2018/09_11_2018_Karstadt_Kaufhof.html (Accessed February 27, 2024).

Coyle, B. D., and Ellison, B. (2017). Will consumers find vertically farmed produce "out of reach"? *Choices* 32 (1), 1–8. doi:10.22004/AG.ECON.253382

Dempsey, N., Bramley, G., Power, S., and Brown, C. (2009). The social dimension of sustainable development: defining urban social sustainability. *Sustain. Dev.* 19 (5), 289–300. doi:10.1002/sd.417

Despommier, D. (2010). The vertical farm: feeding the world in the 21st century. *Picador*.

Deutsche Stiftung Weltbevölkerung (2024). Weltbevölkerung. Available at: https://www.dsw.org/weltbevoelkerung/ (Accessed February 27, 2024).

DLG (2023). Vertical Farming: Mögliche Unterschiede von Rohstoffen aus Indoor-und Outdooranbau. Available at: https://www.dlg.org/de/lebensmittel/themen/publikationen/expertenwissen-foodchain/vertical-farming (Accessed February 27, 2024).

Douglas, J. (2006). *Building adaptation*.

Fischer, H. (2012). Historischer Überblick über den Handel in Europa. Available at: https://geschichte-wissen.de/blog/author/maxdorfer/ (Accessed February 27, 2024).

Freight Farms (2020). *It's time to grow*. Available at: https://www.freightfarms.com/ (Accessed February 27, 2024).

Freight Farms (2024). *Start container farming*. Available at: https://grow.freightfarms.com/get-a-quote (Accessed on February 27, 2024).

Friedrich, J. (2020). Wie lösen wir uns aus dem Klammergriff der ökonomischen Ausquetschung? *Bauwelt*. Available at: https://www.bauwelt.de/dl/1573732/artikel.pdf (Accessed February 27, 2024).

Gageanu, I., Tabarasu, A., Gheorghe, G., Nitu, M., and Pruteanu, A. (2023). Controlled plant growth in vertical farming systems. *Tech. Romanian J. Appl. Sci. Technol.* 14, 85–89. doi:10.47577/technium.v14i.9684

Handelsblatt (2023). Welche 47 Filialen von der Schließung betroffen sind. Available at: https://www.handelsblatt.com/unternehmen/handel-konsumgueter/galeria-karstadt-kaufhof-welche-47-filialen-von-der-schliessung-betroffen-sind/29032824.html (Accessed February 27, 2024).

Hangebruch, N., and Othengrafen, F. (2022). Resilient inner cities: conditions and examples for the transformation of former department stores in Germany. *Sustainability* 14 (14), 8303. doi:10.3390/su14148303

Heimbüchel, B. (2001). *Erlebniswelt Kaufhof: ein warenhaus in deutschland*.

Heynkes, J. (2019). *Zukunft 4.1: Warum wir die Welt nur digital retten – oder gar nicht*.

Jager, A. (2020). *Umbaukultur: Für eine Architektur des Verständnis*. Dülmen: Verlag Kettler.

Lotze-Campen, H., Müller, C., Bondeau, A., Rost, S., Popp, A., and Lucht, W. (2008). Global food demand, productivity growth, and the scarcity of land and water resources: a spatially explicit mathematical programming approach. *Agric. Econ.* 39, 325–338. doi:10.1111/j.1574-0862.2008.00336.x

Mishra, S., Khoda, K., Yau, Y.-Y., and Easterling, M. (2021). *Vertical cultivation: moving towards a sustainable and eco-friendly farming*. Springer Nature, 487–507. doi:10.1007/978-981-16-9001-3_20

National Geographic (2022). Vertical Farming: High-Tech-Gemüse aus der Großstadt. Available at: https://www.nationalgeographic.de/umwelt/2022/02/vertical-farming-high-tech-gemuese-aus-der-grossstadt (Accessed February 27, 2024).

NPS (2018). Hydroponics: a better way to grow food. Available at: https://www.nps.gov/articles/hydroponics.htm (Accessed February 27, 2024).

Obsolete Stadt (2020). Modellannahmen bis 2030. Available at: https://obsolete-stadt.net/wp-content/uploads/2022/09/03_Hamburg_Modellannahmen_220808.pdf (Accessed February 27, 2024).

Okroy, M. (2015). *Das Warenhaus Tietz in Wuppertal: Tempel des Konsums und Ort der Moderne*. Wuppertal: Trägerverein Begegnungsstätte Alte Synagoge Wuppertal e.V.

Prüße, U., Hüther, L., and Hohgardt, K. (2001). Mittlere Gewichte einzelner Obst- und Gemüseerzeugnisse. Available at: https://www.bvl.bund.de/SharedDocs/Downloads/04_Pflanzenschutzmittel/rueckst_gew_obst_gem%C3%BCde_pdf.pdf?__blob=publicationFile (Accessed February 27, 2024).

RegioData Research (2024). Department stores: outdated model for 50 years. Available at: https://www.regiodata.eu/en/europe-department-stores-outdated-model-for-50-years/ (Accessed February 27, 2024).

Rnd (2020). Warum "Vertical Farming" lebenswichtig für die Weltbevölkerung werden könnte. Available at: https://www.rnd.de/wirtschaft/warum-vertical-farming-lebenswichtig-fur-die-weltbevolkerung-werden-konnte-KDIOIA7Q6BGLFBZSYWNXZJYDCQ.html (Accessed February 27, 2024).

Rnd (2021). Vitrine statt acker: start-up Infarm wird zum unicorn. Available at: https://www.rnd.de/wirtschaft/infarm-berline-lebensmittel-start-up-wird-zum-unicorn-EZO5JRP5NBHPXBRXWFYPM3GWZ4.html (Accessed February 27, 2024).

Sharma, R., and Bakshi, P. (2022). Vertical farming an innovative approach for horticulture sector. Available at: https://www.researchgate.net/publication/364282109_VERTICAL_FARMING_An_Innovative_Approach_For_Horticulture_Sector (Accessed February 27, 2024).

Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., et al. (2014). Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings. *Agric. Hum. values* 31, 33–51. doi:10.1007/s10460-013-9448-4

Statista a (2024). Anzahl der Kauf-und Warenhäuser in Deutschland in den Jahren 2004 bis 2019. Available at: https://de.statista.com/statistik/daten/studie/343146/umfrage/kauf-und-warenhaeuser-in-deutschland/ (Accessed February 27, 2024).

Statista b (2024). Anzahl der Warenhaus-Standorte von Galeria Karstadt Kaufhof in Deutschland in den Jahren 2020 bis 2021/22. Available at: https://de.statista.com/statistik/daten/studie/1375924/umfrage/anzahl-filialen-von-galeria-karstadt-kaufhof/(Accessed February 27, 2024).

Tooy, D., Maruf, M. I., Parandy, L. M., and Barki, K. (2023). Towards global food security: vertical farming as an innovative solution. *Endless J. Future Stud.* 6 (3), 335–347. doi:10.54783/endlessjournal.v6i3.229

United Nations (2024). Sustainable development Goals (SDGs). Available at: https://www.un.org/en/common-agenda/sustainable-development-goals (Accessed February 27, 2024).

United Nations Department of Economic and Social Affairs, Population Division (2022). *World population prospects 2022: summary of results*. UN DESA/POP/2022/TR/NO. 3.

WDR (2023). Leerstehende Kaufhäuser: 5 Beispiele für eine neue Nutzung. Available at: https://www1.wdr.de/kugelzwei/gamechanger/leerstehende-kaufhaeuser-100.html (Accessed February 27, 2024).

Westfälischer Anzeiger (2023). Kaufhof in Wuppertal schließt: wie könnte es weitergehen? Available at: https://www.wa.de/nordrhein-westfalen/kaufhof-in-wuppertal-schliesst-so-koennte-es-weitergehen-92466447.html (Accessed February 27, 2024).

Wirtschaftswoche (2024). Karstadt-Kaufhof-Chronik: Aufstieg und Absturz eines Giganten. Available at: https://www.wiwo.de/unternehmen/handel/deutsche-warenhaeuser-karstadt-kaufhof-chronik-aufstieg-und-absturz-eines-giganten/25704944.html (Accessed February 27, 2024).

Zhang, Z. (2023). Analysis of the transformation of the department store industry under the digital economy. *Proc. 2nd Int. Conf. Financial Technol. Bus. Analysis* 54 (1), 107–114. doi:10.54254/2754-1169/54/20230904

Zhuang, Y., Lu, N., Shimamura, S., Maruyama, A., Kikuchi, M., and Takagaki, M. (2022). Economies of scale in constructing plant factories with artificial lighting and the economic viability of crop production. *Front. Plant Sci.* 13, 992194. doi:10.3389/fpls.2022.992194