Design knowledge of urban agriculture providing ecosystem services

A systematic literature review

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DOI
10.1016/j.ufug.2024.128522

Publication date
2024

Document Version
Final published version

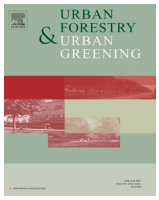
Published in
Urban Forestry and Urban Greening

Urban Forestry & Urban Greening 101 (2024) 128522

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug



Review article

Design knowledge of urban agriculture providing ecosystem services. A systematic literature review

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ARTICLE INFO

Keywords:
Urban agriculture
Ecosystem services
Empirical research
Design research
Research through design
Design knowledge

ABSTRACT

Urban agriculture is acknowledged as a multifunctional integrated concept capable of delivering various ecosystem services. Design-related empirical research which is regarded as crucial for introducing and exploring the transformation of design knowledge and practice. Despite the growing body of scientific evidence, operational guidelines for this topic are relatively scarce. The primary step in promoting practical value involves reviewing existing design knowledge and transformation status in empirical research. In conjunction with the existing design research findings, research through design is the only way to acquire and test design knowledge. Spatial design is acknowledged as a way to translate theoretical concepts into practical applications. This systematic literature review offers a comprehensive qualitative analysis of urban agriculture, ecosystem services, and design research. Additionally, it utilizes bibliometric visualization tools to clarify existing research gaps and propose reliable solutions. This paper reveals the imbalance of design research in delivering ecosystem services in urban agriculture through the review of 70 selected empirical research articles. The results suggest that the research for design approach is the most prevalent and offers abundant design knowledge. However, the relatively infrequent use of the research through design method obstructs the transition from implicit to explicit design knowledge, resulting in a shortage of available operational guidelines. Consequently, the study proposes a framework for systematic design knowledge of urban agriculture to catalyze the transformation of design knowledge. Finally, we outline the framework's composition and logic and elucidate its role in addressing research gaps.

1. Introduction

Agriculture is a prerequisite for food stability, poverty alleviation, and political stability, providing strong support for urban development and progress (Bezemer and Headey, 2008). Urban agriculture, as a multifunctional system (Langemeyer et al., 2021), is widely involved in urban development issues (Filippini et al., 2019). One of the most basic contributions of urban agriculture is providing food for households (Poulsen et al., 2015), as well as other food-related welfare aspects, such as improving food security and enhancing resilience of the food system (Badami and Ramankutty, 2015; Horst et al., 2024). Furthermore, increasing evidence demonstrates the social, economic, and environmental benefits of urban agriculture beyond food production (Langemeyer et al., 2021; Kulak et al., 2013; Park et al., 2019; Azunre et al., 2019, Pradhan et al., 2023). These additional values include strengthening community connections (Carolan and Hale, 2016), providing educational opportunities (Ilieva et al., 2022), improving soil water infiltration (Hallett et al., 2016), mitigating the urban heat island effect (Dieleman, 2017), and fully utilizing urban organic waste, among others (Orsini et al., 2013). In the context of urbanization, climate change, equitable economic models and health issues, are driving urban agriculture from the periphery to the core of discussions (Bohn and Viljoen, 2011). Recognizing the extensive synergies of urban farms and gardens to ensure urban quality of life and reduce ecological footprints is a key indicator for ensuring the normal operation of cities (Larissa and Ana, 2013; Siegner et al., 2020). But the diversity of urban agriculture forms (Dossa et al., 2011) and the complexity of urban systems (Rydin et al., 2012) increased the difficulty in exploring planning and design for the provision of ecosystem services. More importantly, urban agriculture is often an afterthought (Meharg, 2016). Urban agriculture initially undertaken is often an informal agricultural activity (De Bon et al., 2010). The multidimensional value of urban agriculture is not the original purpose of this action. For example, Detroit has revealed the importance of adopting a holistic approach that understands urban

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https://doi.org/10.1016/j.ufug.2024.128522
Received 8 August 2024; Received in revised form 14 September 2024; Accepted 17 September 2024
Available online 18 September 2024

agriculture as intertwined within a complex socio-ecological system of governance, equity, culture, and nature (Newell et al., 2022). However, Detroit originally only sought to ameliorate the decline by achieving food relief through urban agriculture (Colasanti et al., 2012). Fortunately, urban agriculture has subconsciously made unintended contributions.

There are multiple terms used to elucidate the multifaceted value of urban agriculture, such as sustainability (Specht et al., 2014), resilience (Gulyas and Edmondson, 2021), and multifunctionality (Lovell, 2010). Furthermore, research on ecosystem services also provides perspectives for understanding the value of urban agriculture (Aerts et al., 2016; Lin et al., 2015; Deksissa et al., 2021). From the Millennium Ecosystem Assessment (2005), ecosystem services are defined as the various benefits that humans obtain from ecosystems, including provisioning, regulating, cultural, and supporting services. As part of ecosystems, urban agriculture both provides and relies on ecosystem services (Zhang et al., 2007). Many scholars have fitted urban agriculture into the framework of ecosystem services to demonstrate its wide-ranging benefits (Evans et al., 2022; Clinton et al., 2018; Wilhelm and Smith, 2018). Additionally, agricultural systems also depend on the natural environment (such as forests and wetlands) and the ecosystem services they provide to operate (Power, 2010). The close connection between urban agriculture and ecosystem services has been widely discussed (Huang et al., 2015; Artmann and Sartison, 2018). This phenomenon urges us to create a design method that optimises the ecosystem services of urban agriculture with integrated and regional actions. (Mulya et al., 2023). However, despite the growing interest in urban agriculture within the scientific community laying a solid theoretical foundation for urban agriculture practice, integrating urban agriculture into spatially constrained urban landscapes still faces significant challenges (Lin et al., 2015). It is undeniable that we have learnt a great deal about the theoretical concepts and values, and we have also witnessed many applications and practices of urban agriculture. However, knowledge from academic design research programmes does not always help design professionals to enhance their work (Zielhuis et al., 2022). So, how can we use design as means to explore or establish the connection between theory and practice? And how can we connect knowledge of urban agriculture to design?

In order to fill the current gap of insufficient knowledge in practice design, examining the relationship and current status of research and design in urban agriculture and ecosystem services is an igniter for advancing practical exploration. Design research plays an important role in the design discipline because design can consciously create and shape objects that did not exist before and play a lasting role in the real world (Fallman, 2007). Creating design knowledge is a process that presupposes an acknowledgement of the role of design and an in-depth exploration of the links between design and research. In design epistemology, design has long been recognised as a discipline (Cross, 2018), which lays a foundation of design research. In the field of landscape architecture, discussions about the connection between design and research emerged early on (Dorst, 1997). As an applied science, landscape architecture needs to enrich and propel its methodological reservoir through strengthening research on design (Lenzholzer et al., 2013). Design guidelines are a direct and important output of design research to produce efficient and effective designs (Prominski, 2016). In practice, the use of design methods and guidelines works by placing the designer outside of intuition and preconceptions to think about problems and make subjective judgements (Lloyd, 2019). In addition, among design-related disciplines, besides design outcomes, design knowledge can also be regarded as research results (Lenzholzer et al., 2018). This spatial design knowledge forms the basis of creative design in landscape architecture (Nijhuis and Bobbink, 2012). One of the current paradoxes is that practitioners do not know how to implement the grounded theories presented earlier (Makri and Neely, 2021). It is important to recognise that design knowledge and guidelines are two different design research findings and have a mutually reinforcing and influential relationship (Zhang et al., 2011). Translating design knowledge into material that is applicable by designers is the very first step in advancing practice. Particularly in the area of ecosystem service provision in urban agriculture, the paucity of available operational guidelines urges academics to accelerate the rate of transition of design knowledge.

The point of effort in research and design correlation and translation is to dismantle and analyse each logic and state of the dynamic process. Since the last century, Sir Christopher Frayling first categorized design research into Research for Design, Research into Design, and Research through Design when discussing design research in art and design disciplines. Subsequently, Cross (1999) classified design research into design epistemology, design praxiology, and design phenomenology, focusing on designers, the design process, and design products, respectively. In recent years, with the deepening of design research, there have been more advances in the classification of research and design associations. In the field of landscape architecture, according to Nijhuis and de Vries (2020), design research can be classified as research for design, research on design, research through design, and research about design. In the narrative that follows, this will be used to cluster and present the results of the design research and to highlight the role of design practice within it. Research for design emphasizes research providing information, guidance, validation, and development for design practice (Godin and Zahedi, 2014). Research on design refers to supporting the future through the study of design concepts and principles (Nijhuis and de Vries, 2020). Particularly, reviewing precedents is a primary source of design knowledge in practice (Cortesão and Lenzholzer, 2022). Research through design can be understood as viewing a practical design action process as research (Nijhuis and Bobbink, 2012), such as participatory design (Frankel and Racine, 2010). Design knowledge not only exists in the products of design itself but also in the strategies and tactics during the design process (Cross, 1999). Research about design interprets the importance of design processes, methods, and thinking through the study of designers' workflows (Buchanan, 2007). In summary, design research can create singularities, turning theory into practice, and reshaping theory in a whole new light (Lunenfeld, 2003). However, because of their systemic interrelations, it's challenging to accurately differentiate these methods from each other (Tieben, 2015). Therefore, acquiring and applying information is interactive and iterative (Milburn and Brown, 2003), which also ensures the existence of a cyclic inherent relationship between research and design. In summary, a systematic literature review of design research of urban agriculture providing ecosystem services can produce a solid methodological basis for addressing current gaps in the field.

The object of this systematic literature review is design-related empirical research in the field since the 21st century. Many design knowledge regarding urban agriculture and ecosystem services stem from empirical studies (Feng and Zhou, 2014; Sanyé-Mengual et al., 2018; Ruoso et al., 2015). These cases and practical actions provide ample material for design research. An action perspective review of the current research on the design of urban agriculture for the provision of ecosystem services will facilitate ideas for future design and planning guidelines (Fig. 1). Therefore, this review aims to bridge the gap by answering the following questions: What is the status of research on urban agriculture and ecosystem services? What design research methods are used in studies on the provision of ecosystem services by different types of urban agriculture? How will design research facilitate the transformation of urban agriculture design knowledge into operational strategies?

2. Methods and materials

This study aims to synthesise and analyse the potential operational value of ecosystem service provision by urban agriculture in empirical studies through a systematic literature review. Within the framework of the design study, the results of the acquired review are used as a basis for proposing an action perspective strategy. To this end, the literature

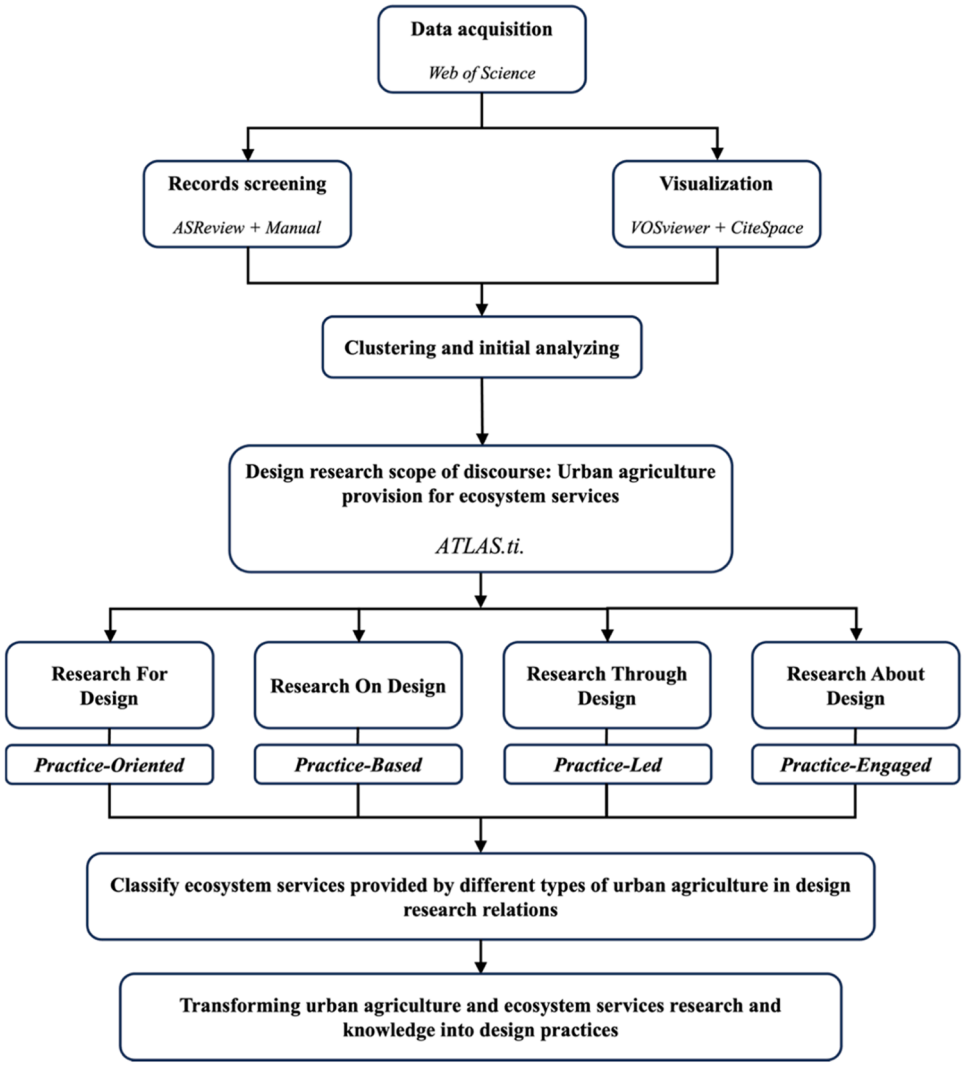

Fig. 1. Workflow of the literature review.

review for this synthesis consisted of two parts. The first was the search and screening of publications. The second was the scientometric analysis of the selected publications.

2.1. Documentation retrieval

We followed the PRISMA statement (Page et al., 2021) to retrieve literature. A comprehensive keyword search can cover a wide range of literature (Pradhan et al., 2023). Literature in the mature database Web of Science covers a large number of publications to elucidate the relationship between urban agriculture and ecosystem services. We conducted the search on this database on April 8, 2024. The search string includes urban agriculture and its synonyms, ecosystem services and its synonyms, as well as case and its synonyms. The complete search string is shown in Box 1. The time spans is from January 1st, 2000 to April 1 st, 2024. After the search, we obtained 2624 papers in total.

2.2. Literature screening

Screening the literature needs to align with the research objectives (Kastner et al., 2012). Because the review aims to explore the performance of urban agriculture practices in providing ecosystem services, the task of screening "examples" is cautious and challenging. Therefore, we chose to use a combination of machine learning and manual

Box1
Search string in this review.

(TS=(urban* OR city OR peri* OR community* OR domestic*) AND TS= (agriculture* OR garden* OR farm* OR food* OR edible OR cultivat* OR horticulture)) AND (TS=(ecosystem* OR environment*) AND TS=(service* OR benefit* OR provide*) AND TS=(regulat* OR support* OR provision* OR cultur*)) AND (TS=(case* OR example* OR evidence* OR project* OR experience*)) AND (TS=(design OR planning OR landscape*))

screening for the selection process. ASReview is a tool for active learning in systematic reviews by screening titles and abstracts (Scherhag and Burgard, 2023). Compared to manual screening alone, active learning is more effective and yields higher quality results (Van De Schoot et al., 2021). However, to ensure the accuracy of machine learning, we manually checked the results of the screening and conducted a second screening for papers marked as "irrelevant" by machine learning. According to the PRISMA flowchart (Fig. 2), we first excluded 1 duplicate paper and 72 non-English papers. Before machine learning screening, 420 non-article papers and those without full-text information (n=6) were excluded. The remaining papers eligible for assessment (n=2127) were trained using ASReview and subsequently manually checked. Based on the research objectives and questions, 2057 papers were removed due to irrelevant research topics (e.g., microbial ecosystems, forest ecology), unrelated disciplines (e.g., toxicology, astronomy), and ambiguous case locations and scopes (e.g., global scale, North and South hemispheres). Finally, the scope was narrowed down precisely to 70 papers for future analytical use.

2.3. Scientometric analysis - VOSviewer and citespace

Scientometric analysis refers to the quantitative study of scientific development (Yalcinkaya and Singh, 2015). It is a technique for evaluating research impact and investigating citation relationships by mapping trends extracted from academic databases to specific knowledge domains (Ghaleb et al., 2022). In this study, we utilize scientometric techniques to provide visual information (Börner et al., 2003). VOSviewer is a tool used to construct and visualize literature networks (Van Eck and Waltman, 2017). This visualization aids in expanding understanding of a given topic direction (Arruda et al., 2022). Additionally, CiteSpace is used to generate and analyse co-citation networks based on bibliography records retrieved from the Web of Science (Chen et al., 2012). Its main objective is to facilitate the analysis of new trends in knowledge domains and allow users to create time series snapshots and merges for a particular field (Chen, 2006). Therefore, we decide to combine VOSviewer and CiteSpace to visualize the keyword information, frequency, and clustering of the selected literature to depict current research hotspots and connections.

2.4. Literature coding

We carry out the coding exercise for the screened literature by ATLAS.ti. ATLAS.ti is a qualitative analytical data software developed by the Technical University of Berlin for analysing text documents and establishing intra-textual associations (Adelowotan, 2021; Silver and Lewins, 2014). The main purpose of literature coding is to organise

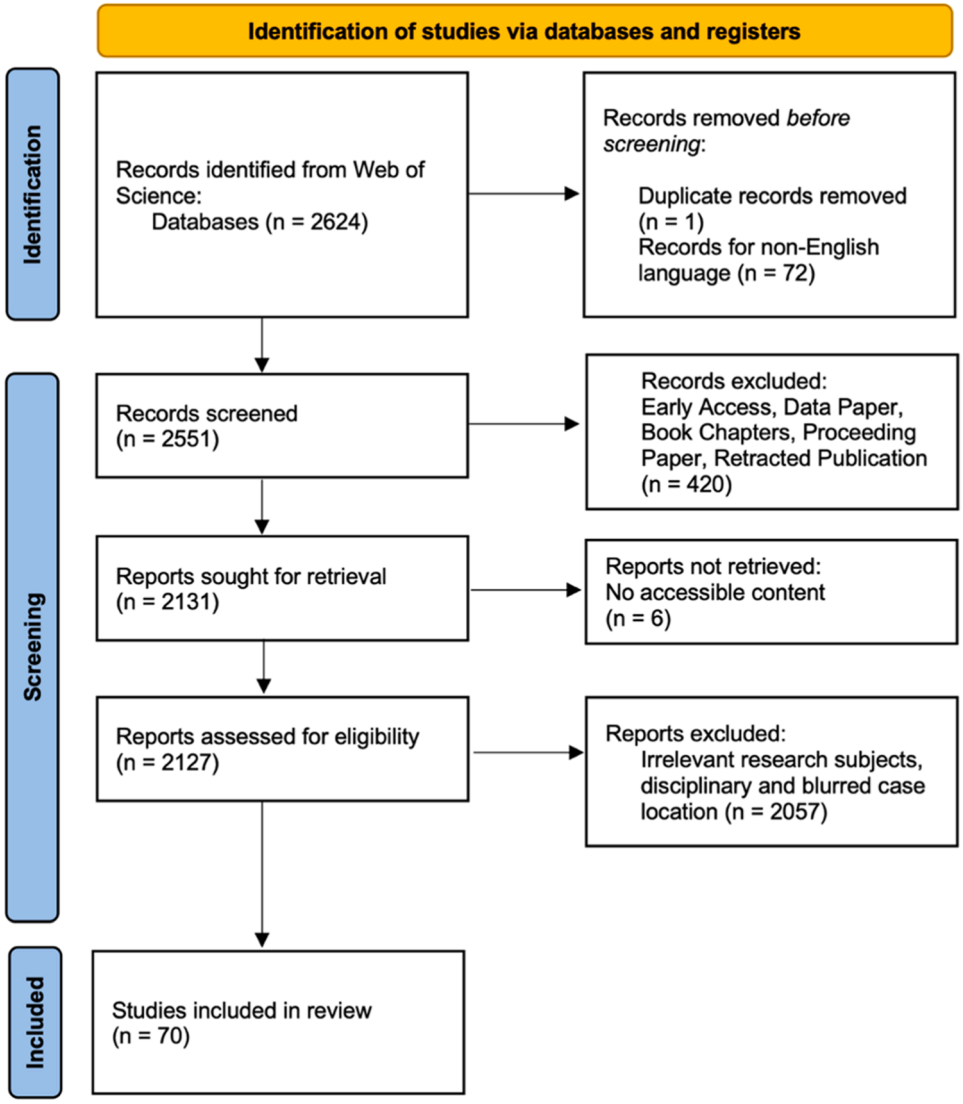

Fig. 2. PRISMA process diagram for literature screening.

scientific findings through emerged categories (Ronzani et al., 2020). Therefore, categorisation criteria are at the forefront of literature coding. Given the purpose of the study, we decide to adopt the design research approach in the discipline of landscape architecture proposed by Nijhuis and de Vries (2020) as a guideline for category identification, i.e. research for design, research on design, research through design and research about design. Firstly, we categorize the literature based on the above guidelines after a careful reading. And then, we establish a networked relationship between them by extracting information from the literature under the categories of urban agriculture and ecosystem services. Finally, we obtain the focus of current research and the potential for future development by counting the frequency with which urban agriculture is discussed under each of the design research categories. These analytical processes and findings can effectively lead to the path to address research gaps.

3. Results

The time interval selected for this review is from 2000 to 2024. However, empirical research on urban agriculture and ecosystem services began after 2007 and saw a gradual increase after 2012 (Fig. 3). This phenomenon indicates that before 2007, researchers did not emphasize the potential connections between urban agriculture and ecosystem services from an operational perspective. It is worth noting that while there was a significant booming of empirical research from 2016 to 2020, it was followed by a decline afterwards. This implies that there is a gap in contemporary research in the field and that it needs to be addressed urgently. In addition, the distribution of countries in which papers are issued shows a significant increase in national involvement since 2012, although 2015, 2017, and 2024 are exceptions. 2020 presents the peak of research fervor at the national level. Again, corresponding to the trend in the number of publications, there is a decline in national participation from 2020 onwards. Comprehensively reviewing, Germany, the United States, Italy, Australia and China are the head echelon of research in this field.

Additionally, we found that the mutual connections between countries are not very strong (Fig. 4). Germany and Norway have relatively close collaborative relationships. This indicates that conducting research on this topic from a multinational perspective is relatively challenging, which may be related to the need for extensive field investigations of cases and interviews/questionnaires with stakeholders.

In addition, through the network of co-operative relationships, we find that country-to-country interconnections are not very strong (Fig. 4). Germany and Norway are the ones with more cohesive and more active external co-operations. This indicates that conducting research on this topic is relatively challenging in the perspective of cross-national environments. It can be accompanied by a number of reasons, such as the need for extensive field investigations on the cases, interviews and questionnaires with local stakeholders, and the variability between national contexts and research foundations.

3.1. Preliminary review of visualisation

VOSviewer provides results on keyword co-occurrence and network association (Fig. 5). Urban agriculture, ecosystem services, landscape, and garden respectively emerge as the most highly co-linear expressions within four clusters. Simultaneously, this study aims to discuss the current application status and potential of design research methods in empirical studies. The close association between terms such as practice, case, project, used to describe practice, and the presented themes illustrates the high usability of the literature sample, laying a foundation for further discussion.

Citespace-produced information is mainly used to illustrate the hotspots, emerging trends, and temporal zones of urban agriculture and ecosystem services empirical research since 2000. From Fig. 6a and 6c, it can be seen that urban agriculture and ecosystem services are the most prominent and continuously monitored topics. The terms with the highest degree of co-occurrence all appeared early in the study and have far-reaching implications. "Community gardens" and "biodiversity" respectively serve as their representative subsets and have been discussed for a long time. These discussions are also primarily considered important topics by the "landscape" discipline. Additionally, through cluster analysis (Fig. 6b), we found that discussions on suburban urban agriculture and ecosystem services mainly revolve around theoretical discussions of "community gardens" and "food security". Discussions related to "design", "planning", and "urban-rural relations" are somewhat lagging behind. Finally, after sorting the top 25 exploding keywords by time (Fig. 6d), we found that there is no continuous linear relationship in the time dimension between terms directly related to design, such as "food planning", "landscape planning", and "urban planning". This indicates that there is a certain difference in the attention to the design process and design outcomes in research in this field. We will elaborate

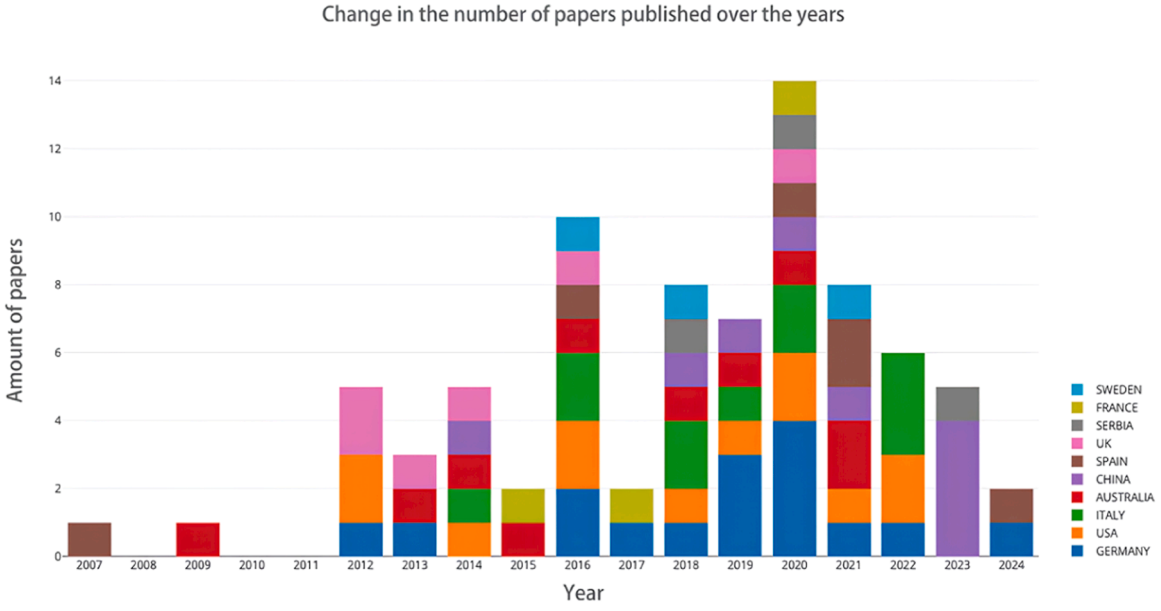

Fig. 3. Number of publications over the years and country distribution.

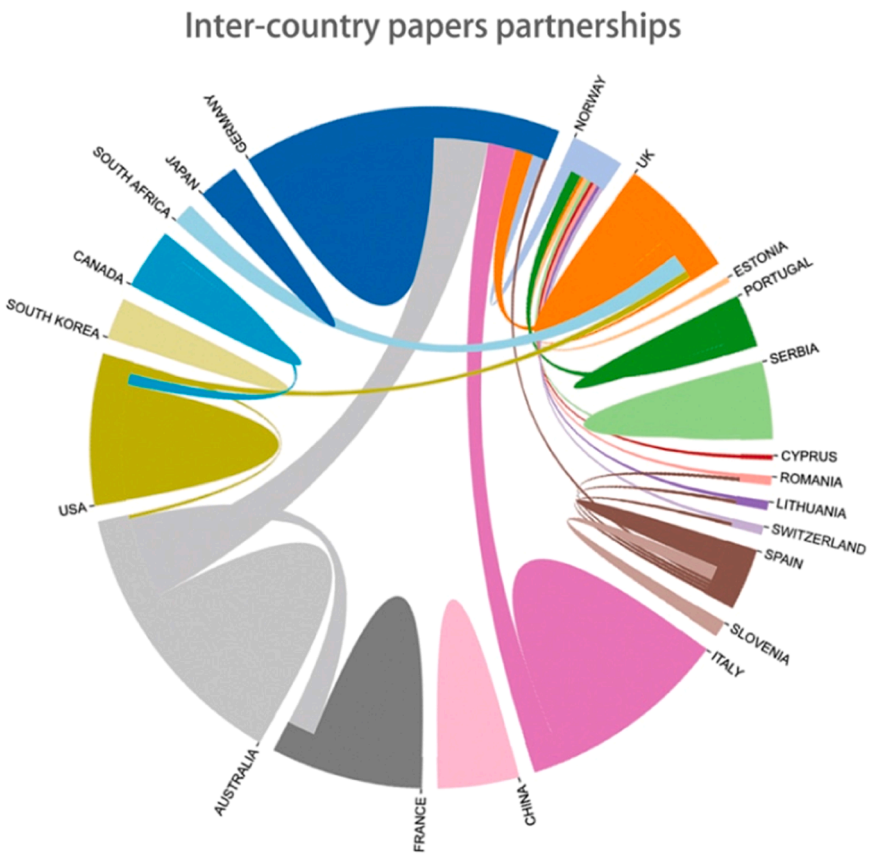

Fig. 4. Inter-country partnerships.

and analyse more on this phenomenon in subsequent chapters.

3.2. Provision of ecosystem services by urban agriculture in empirical studies

We summarised the topics of urban agriculture and ecosystem services discussed in the screened documents after literature coding. The purpose of this step is to clearly identify the differences in attention to different types of urban agriculture and ecosystem services in existing empirical research. Given the multitude of taxonomical studies on these two topics, the strategy of this study is to appropriately add and merge similar expressions from empirical research based on the recognised taxonomies in existing studies. Urban agriculture can be broadly classified into agriculture activities within the city and suburban areas (Mougeot, 2000). Considering the thorough review required by the research, we summarised and divided types of urban agriculture in the selected documents based on existing classification methods (Van Tuijl et al., 2018; Opitz et al., 2016; Audate et al., 2019). Thus, for urban agriculture, peri-urban agricultural farm is the most discussed, followed by community garden, productive urban landscape system, urban garden, and so on (Fig. 7a). Similarly, the classification of ecosystem services is enriched based on the findings of previous research (Wallace, 2007). The review shows that the provisioning service of food production is the most significant contribution of urban agriculture research. In general, cultural services and regulating services are discussed more extensively (Fig. 7b).

After independently reviewing the distribution of research hotspots for the two sub-topics, we corresponded all reviewed urban agriculture and ecosystem service types (Fig. 8). As for urban agricultural practices, although the emphasis on functions and services may vary, food production plays a more important role as either the main or ancillary service. Regulating services offer a wider range of function types. When considering individual type of urban agriculture, such as a peri-urban agricultural tourism farm, its main contributions are distributed under the category of cultural services and do not involve regulatory services. In comparison, domestic gardens provide a more comprehensive range of four ecosystem services. To some extent, these findings can indicate the variability between the different types. At the same time, however, the findings are not absolutely representative. For example, number of literature samples selected, areas of expertise and research interests of scholars and different research methods and objectives can all have an impact on the results.

3.3. Design research in ecosystem services provision by urban agriculture

Based on the definitions and characteristics of design research approaches, we categorized the selected literature into different clusters and counted the number of documents included in each category (Table 1). The criteria for classification were based on the definitions and examples of design research methods described in the literature (Nijhuis and de Vries, 2020; Tieben, 2015; Stappers and Giaccardi, 2014). The research for design cluster predominantly employs methods such as usability testing and stakeholder surveys (Tieben, 2015). The quantities of research on design, research through design, and research about design are involved less. Research on design involves studying and reviewing precedent cases and plans to gain inspirations (Nijhuis and de Vries, 2020); whereas research about design involves investigating the work process from the designer's perspective (Lunenfeld, 2003). Research through design often intervenes in the design process through participatory design methods to generate concepts and viewpoints (Zimmerman and Forlizzi, 2014). Also, research through design shows particular concern for the design process (Nijhuis and de Vries, 2020).

In order to visualise the frequency of use of the four methods, the relative proportions of the four methods are presented in Fig. 9.

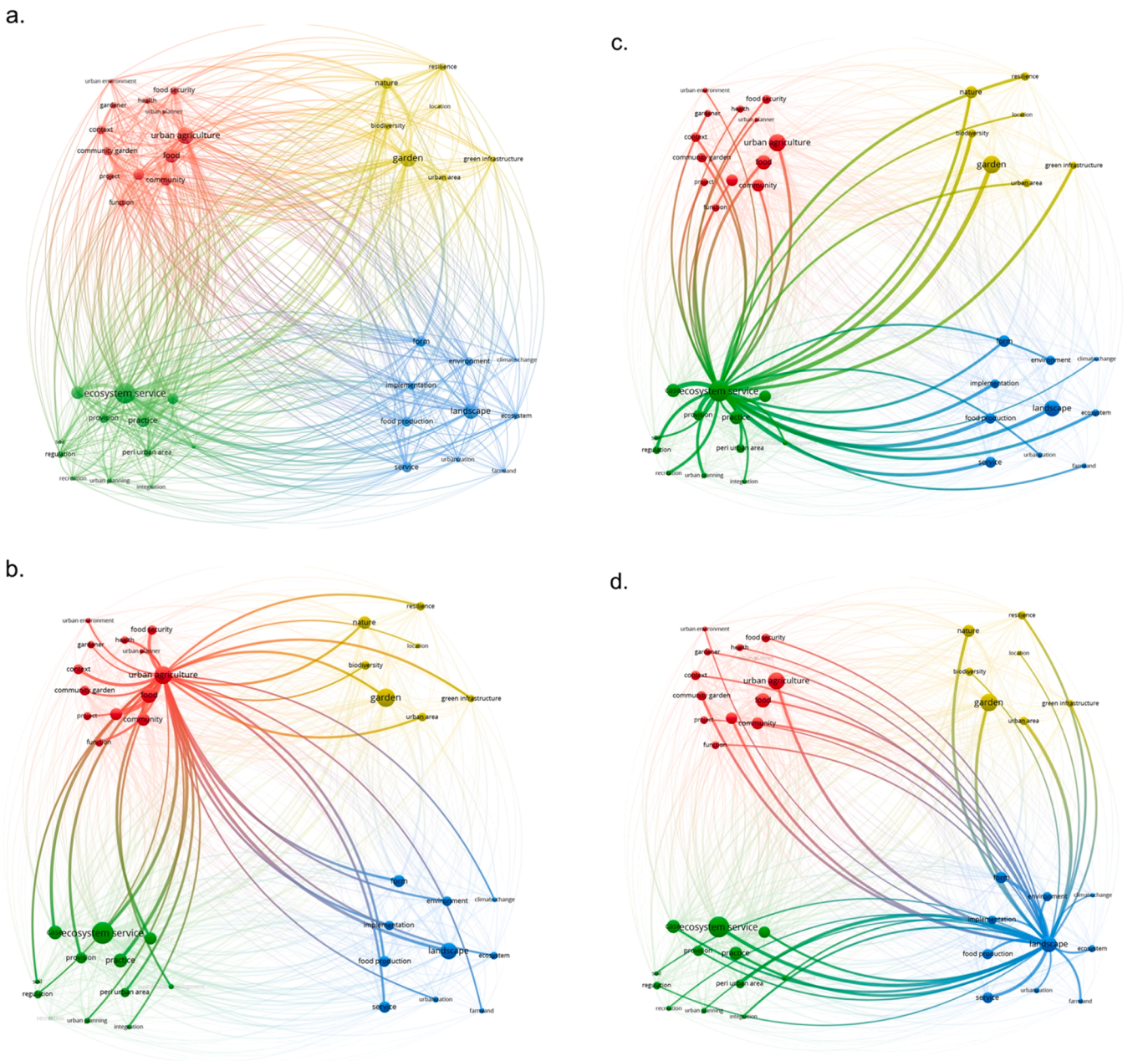

Fig. 5. Keyword co-occurrence and network associations processed by VOSviewer. [a] keyword co-occurrence; [b] research associations for "urban agriculture"; [c] research associations for "ecosystem services"; [d] research associations for "landscape".

Research for design accounts for more than half of the total, suggesting that scholars are contributing to design through a number of qualitatively oriented research methods in the field. This has also been the dominant approach to scientific research. Research about design, research on design and research through design are comparably less because they rely on a designer's perspective and a design-centered research initiative. In particular, research about design and research though design require discussions and implementations about the design process, which makes the available target material more limited. It is precisely because of the lack of design projects and formal practices with detailed design process in urban agriculture that there is a dearth of research led by these methods.

For the next step, we extracted the types of urban agriculture from the classified literature in Table 1 and plotting them by frequency in Fig. 10. The types of urban agriculture and associated ecosystem services that are the focus of each design research approach can be clearly obtained from the corresponding queries in Fig. 8 and Fig. 10. It is evident that the diversity of urban agriculture types addressed by research for design and research on design is relatively high, indicating that scholars have provided ample knowledge for future design practices. It is also closely related to the researcher's passion to study the functionality of global urban agriculture practices. Among these, peri-urban agricultural farm and community garden received the most attention. However, the focus of research through design and research about design which rely on design activities and processes for research, is more limited. It is highlighting issues such as the high difficulty of such research studies, insufficient attention to action perspective, and lack of materials to investigate. Additionally, urban aquaponics, addressed in research through design is not included in research for design and research on design category. This finding indicates a gap between design knowledge and practice and underscoring the weakness in the transformation of theoretical outputs into design layouts.

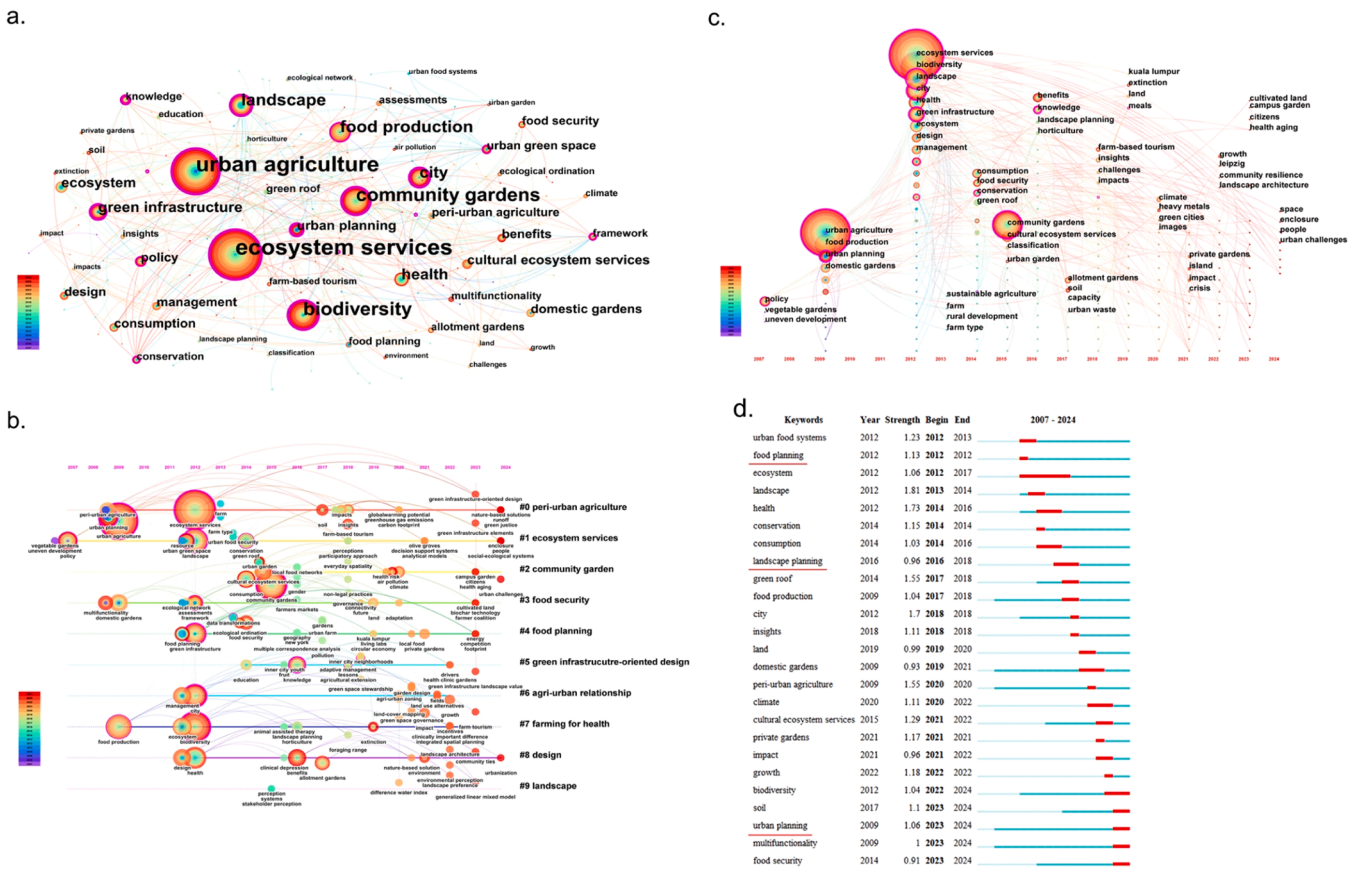

Fig. 6. Citespace results for keyword information. [a] keyword co-occurrence results; [b] keyword clustering and timeline; [c] keyword time zones; [d] 25 keywords with the most explosive citations.

a.

b.

Fig. 7. Typological hotspots in empirical studies. [a] urban agriculture type hotspots; [b] ecosystem services hotspots.

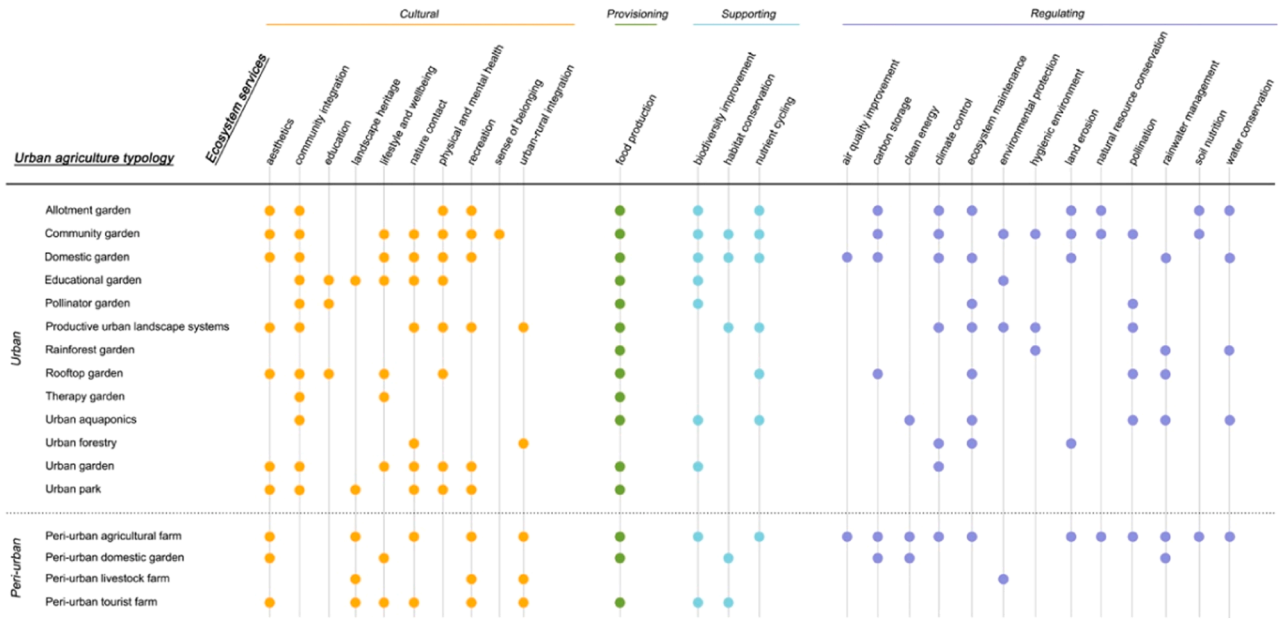

Fig. 8. Relationship between reviewed urban agriculture and provision of ecosystem services.

Table 1
Application of design research in the provision of ecosystem services by urban agriculture.

Design research method	Number of literature	Literature number
Research for design	46	1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15, 17, 20, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 36, 38, 40, 42, 43, 46, 47, 49, 50, 51, 52, 54, 56, 57, 58, 59, 60, 62, 67, 69
Research on design	10	11, 16, 35, 41, 44, 45, 48, 53, 66, 70
Research through design	8	18, 19, 21, 23, 37, 39, 63, 65
Research about design	6	10, 34, 55, 61, 64, 68

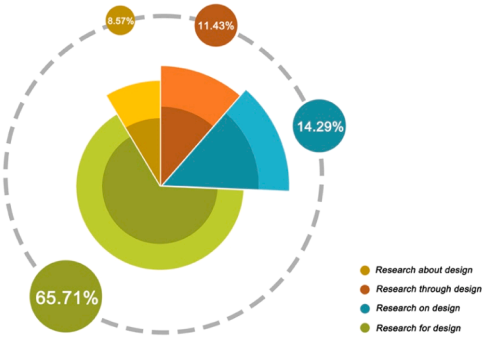

Fig. 9. Percentage of the four design research methods in urban agriculture with ecosystem services empirical studies.

4. Discussion

4.1. Clarifying research gaps: the balance between design knowledge and design actions in urban agriculture for ecosystem services

The previous findings and descriptions reflect the significant role of urban agriculture in providing ecosystem services, particularly in provisioning services (Napawan and Burke, 2016; Stockwell et al., 2013) and cultural services (Hino et al., 2023; Kordon et al., 2022). Based on different research methods, findings can be categorized into three forms: theoretical knowledge, design strategies, and assessment methods and tools. Firstly, Zasada et al. (2013) elucidated the contribution of peri-urban livestock farming in Berlin, Germany, to urban-rural integration, rural economic development, and cultural recreational landscapes using research methods such as surveys. Furthermore, research has found that community gardens can be a useful alternative to traditional food systems and fulfil a range of social and environmental needs (Napawan and Burke, 2016). Productive urban landscape systems have broad potential to improve residents' progress towards healthy lifestyles and promote public health (Hino et al., 2023). Such findings provide strong theoretical evidence for urban agriculture practices. Secondly, Tzortzi et al. (2022) studied peri-urban agricultural planning and design approaches and process in Milan through field surveys, archival analysis, and mapping to provide design strategies for future agricultural-cultural heritage regenerations. In South Korea, experts have proposed a design solution to provide farming education and ecological experiences through the development of Rice-Fish Mixed Farming Paddy in an educational space (Son et al., 2022). These direct inputs into design methods and strategies have greatly enriched the diversity and reliability of design references for practitioners. Thirdly, Caputo et al. (2020) discussed the positive contributions to sustainable agricultural production goals through the application of life cycle assessment-based methods for food production energy and environmental impact assessment in urban renewal processes. Zhang et al., 2023 present a temporal-spatial evaluation tool for assessing changes in three typical ecosystem service functions: food production, water conservation, and recreation. These tools and methods can be used as a tool for feasibility analyses of urban agriculture initiatives and for usage performance assessments.

It is widely believed that research is conducted to generate new knowledge that can be shared (Redström, 2021). The empirical research literature reviewed in this study provides knowledge in various aspects. However, design knowledge typically involves both explicit and implicit knowledge, and the challenge lies in articulating implicit knowledge explicitly (Friedman, 2000). While access to implicit knowledge is also important for landscape architecture, designers prefer to acquire knowledge that has been translated through design language. The translation work is often the task of scholars in the design disciplines.

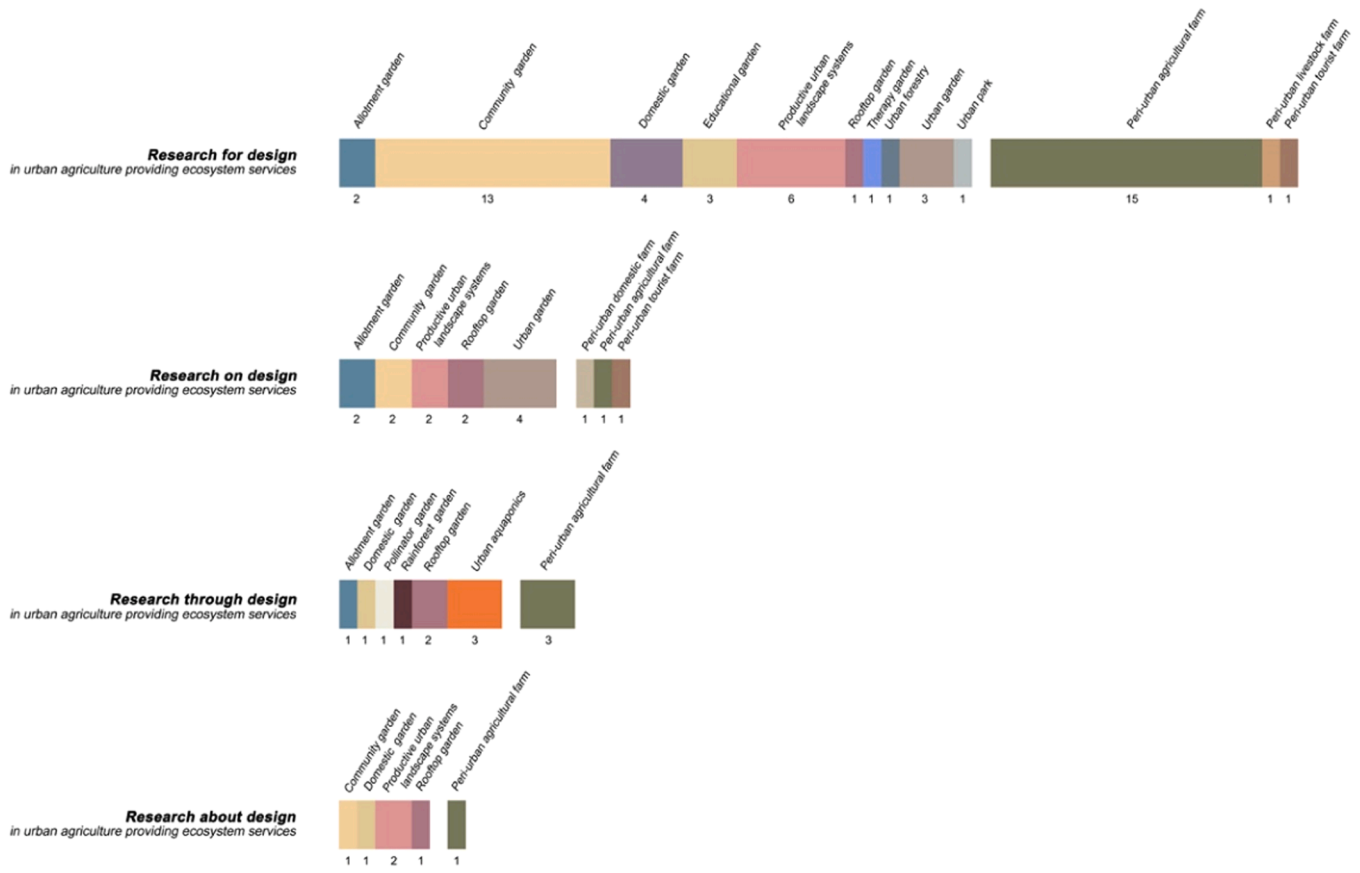

Fig. 10. Frequency of occurrence of urban agriculture types in the four design research methods.

For us, one way to express knowledge explicitly is by applying the acquired knowledge to new designs. In the discipline of design, knowledge is emphasized to inform actions (Augustin and Coleman, 2012). The results of the review indicate a high enthusiasm among scholars in contributing to new knowledge. However, it is undeniable that there is still a gap in the transformative approach of explicit knowledge into implicit knowledge. In other words, while we are aware of the plenty of potentials and benefits of urban agriculture in providing ecosystem services, how to integrate them into urban environments and make them effective remains a major challenge.

4.2. *Diagnostic approach: designing research methods*

Through our review, the gap found in this review is related to the research state of design research approach application in empirical studies. Therefore, we use a relational diagram to link knowledge, research, design activities, and design outcomes to comprehensively explain this contradiction (Fig. 11). Research serves as an engine for generating various innovations (Sarpong et al., 2023), including providing knowledge (Higgs and Titchen, 1998) and design outcomes (Yang, 2005). Specifically, research for design fosters design practices by

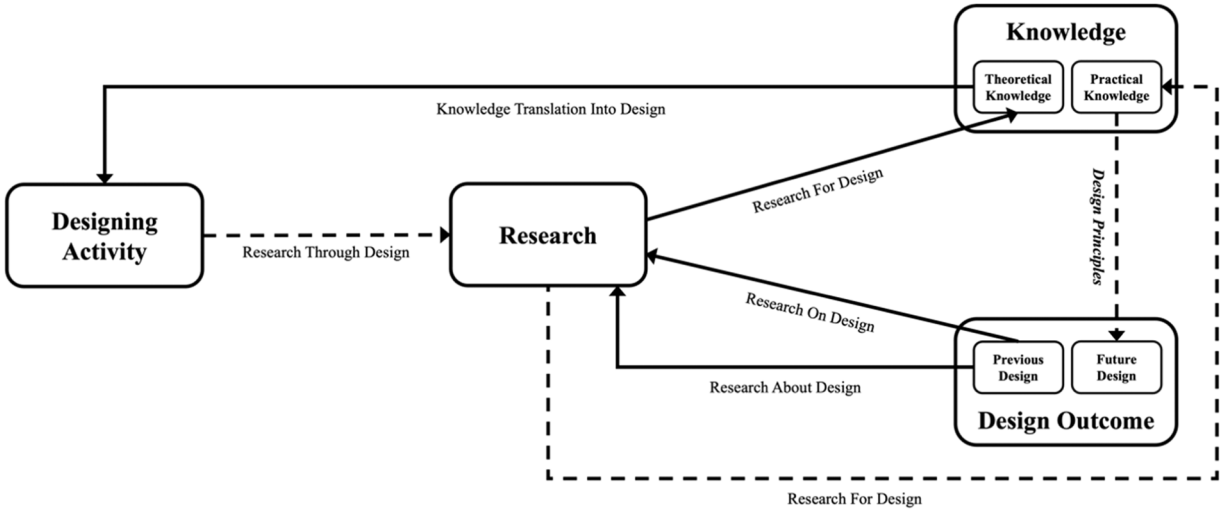

Fig. 11. Network diagram of the design research in the reviewed empirical research.

providing new knowledge and applying it to design activities (Friedman, 2000). These knowledge assets need to be utilized through design as a mechanism for open innovation (Simeone et al., 2017). Beery et al. (2014) explored school gardens for food security in Canada and specifically noted that children gained knowledge to support long-term chronic fatigue syndrome as a result of their participation. These contributions from non-design scholars can be used to support designers and scholars in recognising the scientific basis of urban agriculture in delivering ecosystem services. By research through design, theoretical design knowledge is tested and refined in the real world (Keyson and Bruns, 2009). Through the continuous operation of this cycle, theoretical knowledge is transformed into operational knowledge with higher practical value. Davis and Carter (2014) articulated the role and prioritisation of peri-urban agriculture in biodiversity conservation through qualitative analysis. Subsequently, scholars have borrowed these theoretical findings to propose a framework for designing and implementing green infrastructure at the peri-urban scale (Capotorti et al., 2019). This process of materialising theoretical knowledge is relying on research through design. Meanwhile, design outcomes can play a dual role based on temporal characteristics. Previous designs are observed by research on design process and diagnosed from the perspective of workflow through research about design method (Sileyew, 2019). Son (2018) reviewed the design of a rooftop garden at Seoul National University and demonstrated that appropriate design facilitated the reconnection of disconnected green spaces and created a continuous panorama with the surrounding natural areas and landscapes. This provides a precedent for the future design of rooftop gardens to provide a wide range of cultural services. In addition, the integration of urban agriculture and sustainable cities in Lugo, Spain, is reviewed from a designer's perspective and the role of spatial planning for urban agriculture in enhancing integrated ecosystem indicators is derived (Gómez-Villarino and Ruiz-Garcia, 2021). These processes can be seen as essential safeguards to ensure successful design actions. Future designs are long-term dynamic goals and products based on current knowledge that concretize concepts. They start from operational value and practical knowledge and depict results through design strategies. Research through design is considered a crucial catalyst as design knowledge is contained within ongoing design activities, cognitive processes, and completed artifacts (Faste and Faste, 2012).

Based on the previous discussion, we identified gaps in the provision of ecosystem services in urban agriculture from action perspective: an imbalance between theoretical and practical outputs; and a lack of method for translating implicit design knowledge into explicit design knowledge. By systematic literature review on design research applied in this topic, it is important to point out the necessity and potential of research through design. Research through design is a down-to-earth approach because it does not look at design from a distance, but actively engages with it (Redström, 2021). In addition, research through design has the advantage of providing comprehensive strategies for seeking solutions to problems (Nijhuis and de Vries, 2020). Although the multifunctionality of urban agriculture is widely discussed in theoretical studies (Orsini et al., 2020), its practical performance needs to be verified through authentic design. Relying on research through design, the path of guiding future design by design knowledge becomes tangible.

4.3. The role of design practice: correspondence between design research and action

Design practice is the goal, foundation, motivation and object of design research. As illustrated in the introduction section of the article, there is a correspondence between practice and research. Research for design has design practice as its long-term goal and provides extensive and adequate knowledge for this objective. It is a practice-oriented model because this knowledge can directly or indirectly influence the future direction of design. Research on design treats action as foundation and a starting point. Research is based on previous practice to reflect on innovative proposals. Research through design is not only centered on the final product of the design, but is also concerned with the usability testing of existing design knowledge during the output process. This is a two-way process of review and feedback and is beneficial to the updating and transformation of design knowledge. In other words, practice leads all the research workflow. Complementing this, Research about design looks at the design process from the perspective of frontline practitioners. Design practice is interspersed and engaged throughout the research process.

Through a systematic literature review, we identified the diverse roles played by design practices in empirical studies of ecosystem service provision in urban agriculture and how they contribute to design research. Clearly, design is underpowered in terms of guiding research. Scholars have devoted their full energy to deeply dig into established design outcomes and have lacked the ability to explore how design can lead research. Despite the vast amount of design knowledge that has been gained, it is precisely we are not using design knowledge properly because of lacking testing and critically examining these gains from operational perspective. At the same time, this finding provides ideas about the significance for the translation of design knowledge, namely the hands-on actions of design practitioners.

4.4. A design research methodological framework driven by research through design

Based on the previous findings and discussions, it can be concluded that research through design is highly valuable in transforming the theoretical knowledge of urban agriculture providing ecosystem services into practical knowledge. Therefore, we propose a design research framework driven by research through design (Fig. 12) to address and bridge the gap mentioned earlier.

In this framework, we emphasize three significances:

1) Design research involves a systematic search and acquisition of knowledge related to design and relevant design activities (Bayazit, 2004). The term "design" here is used in a double sense, encompassing both noun and verb meanings (Steinitz, 1995). Therefore, the meaning of design research can also be understood as conducting investigations using dynamic design on static design. Historically, research-led perspectives in design research have a longer history compared to design-led perspectives (Sanders, 2008). This represents both a valuable asset and a significant challenge for future design. On one hand, research-led approaches can provide abundant theoretical support for design actions. On the other hand, persisting in research without considering the translation of outcomes into design language hampers the advancement of design practice. For urban agriculture, the application of design research has become more widespread. Given the findings of this review, a great number of efforts are still needed on design guidelines for accessing ecosystem service provision through research through design approach. The significance is to shift the attitude towards urban agriculture. We need to look at urban agriculture not only as a component of the urban ecosystem but also from a design perspective in terms of how it can be embedded in the urban space. In summary, design research requires us to adopt an integrative action perspective.
2) Research through design serves as a dynamic hub for generating both explicit and implicit knowledge. Its emphasis is on identifying and solving problems in the process. Design knowledge originates from the accompanying processes that occur during the creation of design outcomes (Clarke, 2018). Often, this knowledge can be categorized into directly usable (explicit knowledge) and indirectly usable (implicit knowledge) forms. The dynamism of design is also reflected in its cognitive processes, which are fundamentally different from traditional science (Cross, 1999). Design deals with more variable processes and biased objects (Jonas, 2012). Although design is purposeful, the motivation in design research must be knowledge

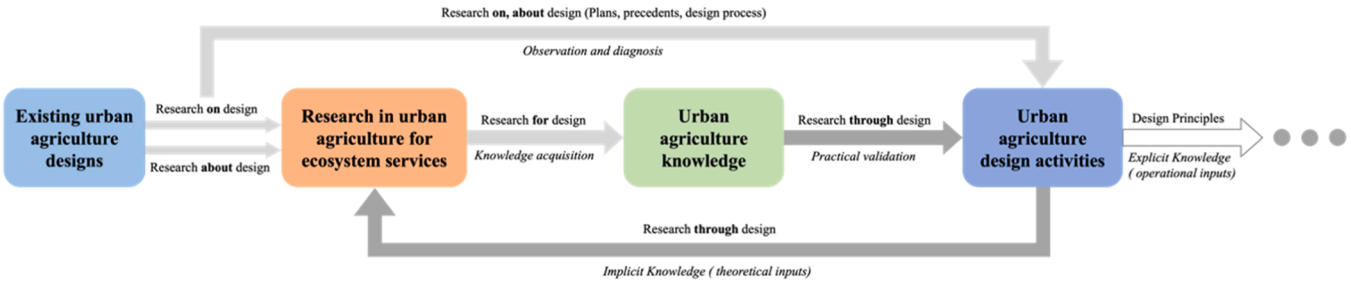

Fig. 12. A design research framework centered on research through design in urban agriculture providing ecosystem services.

production (Zimmerman et al., 2007). Similarly, this presents two choices for research through design: either producing design products based on explicit knowledge or generating implicit knowledge for new research. Through the review, we found that the results of empirical studies using research through design converge towards design outputs. At the same time, because research through design is a dynamic process, there remains a lot of feedback and reflection on theory or earlier design knowledge. Hence, with research through design, design research is no longer a linear assembly line process but a production center with self-circulating system.

3) Research through design can not only provide new design principles and guidelines but can also be used to check whether they can be applied to a broader field. The design process is seen as a process of examination and reflection (Chen and Terken, 2022). Often this is not a one-off event, as the design process is seen as a gradual, iterative process of transformation (Braha and Maimon, 1997). In a continuous cycle, the design outcome can be tested to have extended functionality. Design as an innovation output has a positive externality (Laakso and Kostiainen, 2009). For example, the knowledge that scholars have gained about the design and planning of peri-urban urban agricultural farm has been validated and then used to reflect whether it is feasible to locate it in an intra-urban context. Similarly, rooftop garden design in schools can be considered within the broader context of rooftop gardens practices. This property is significant in facilitating interdisciplinary knowledge exchange and integrated design strategies.

5. Conclusion

This study is a systematic review of empirical research on urban agriculture providing ecosystem services, and utilizes design research methods to explain the phenomenon of inadequate design practice output in this field. The review results visualize the most widely used methods as research for design, while research through design is one of the less used approaches. The lag in operational value is closely related to the insufficient driving force for the transformation of implicit design knowledge. However, through argumentation, research through design is identified as a dynamic process capable of creating and transforming obtained knowledge. Therefore, to provide new insights into addressing this issue, this paper proposes a design research framework driven by research through design to produce knowledge and promote transformative process. Here, we particularly emphasize the necessity, systematicity, and dynamism of design research.

Indeed, this study still has some limitations. Firstly, the sources of literature selected are relatively limited. Many design practices may appear in other types of textual formats, such as design project texts. Although they are often closely related to the research topic, they were not included due to accessibly and lacking scientific contributions. Additionally, the database of the current research used in this review is relatively small, which may affect the representativeness of the research results. In the future, we will focus on addressing these limitations and providing stronger evidence to confirm the role of research through design.

CRediT authorship contribution statement

Yu Huan: Writing – original draft, Visualization, Software, Methodology, Funding acquisition, Data curation, Conceptualization. **Nico Tillie:** Writing – review & editing, Supervision. **Steffen Nijhuis:** Writing – review & editing, Supervision, Project administration, Investigation, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work.

Acknowledgement

This research is funded by the China Scholarship Council (CSC NO.202207720115).

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