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*Review*

# Future Prospects of the Assembly Model for MEP Systems in Chinese Buildings: A Whole Life Cycle Perspective

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**Abstract:** The assembly building M&E (Monitoring and Evaluation) system is a vital part of the transformation of China's construction industry, featuring intelligent control, high efficiency, and high safety. The article provides a comprehensive review of research related to assembly M&E systems from the perspective of the whole life cycle of assembly, containing 125 journal articles from 1993 to 2024. The article analyzes some policies with updated iterations in the United States, Japan, Germany, Denmark, France, and the European Union. The literature review and semi-structured interviews with experts identified significant constraints limiting the various stages of the entire life cycle of assembled MEP (mechanical, electrical, and plumbing) systems. The absence of uniform design standards, personnel collaboration, prefabricated component testing, transportation, information utilization, intelligent testing, and recycling of disassemblability that can occur in the entire life cycle of assembled MEP systems are summarized. Finally, the article suggests that assembly M&E systems can be shared and marketed to improve the economic viability of assembly M&E systems and their wide application in the areas of technology, platform, and demand.

**Keywords:** assembly M&E; PRISMA; entire life cycle; policy



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## 1. Introduction

With China's economic progress and actual national conditions, the demographic structure of China is quietly changing, with the proportion of aging increasing yearly. As labor and material costs continue to rise [1], enhanced environmental protection regulations [2] force the construction industry to reduce the environmental impact of on-site construction. As a result, traditional MEP manufacturing has had to transition to assembly MEP [3]. This is because of its unique advantages, such as factory construction, mechanical assembly, whole-process tracking, less labor required, and high safety. From the national policy point of view, China's "14th Five-Year Plan" construction industry development plan policy [4] indicates that by 2030, the proportion of assembled buildings in new buildings in cities and towns will reach more than 30%. The China Construction Industry Association released the "2022 construction industry development statistics analysis" [5]. The national construction industry enterprises completed construction with a gross output value of 31,197,984,000,000 yuan. The macro policy of the country requires enhancing the proportion of assembly buildings in the whole industry. It can be concluded that the assembly of electromechanical systems has considerable investment space in this field, with electromechanical systems being an essential part of it. MEP engineering is a general term for the management of non-structural functions of the building, such as plumbing, heating, ventilation, air conditioning, electric power, energy savings, elevator maintenance, etc. [6]. It likewise possesses excellent development potential and investment space. Next, this paper summarizes the current research status of assembled MEP systems from the whole life cycle perspective.

## 2. Research Methodology

To ensure methodological rigor, a systematic review of studies concerning safety climate in the construction domain was conducted across three stages (see Figure 1) by following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) protocol guidelines [7].

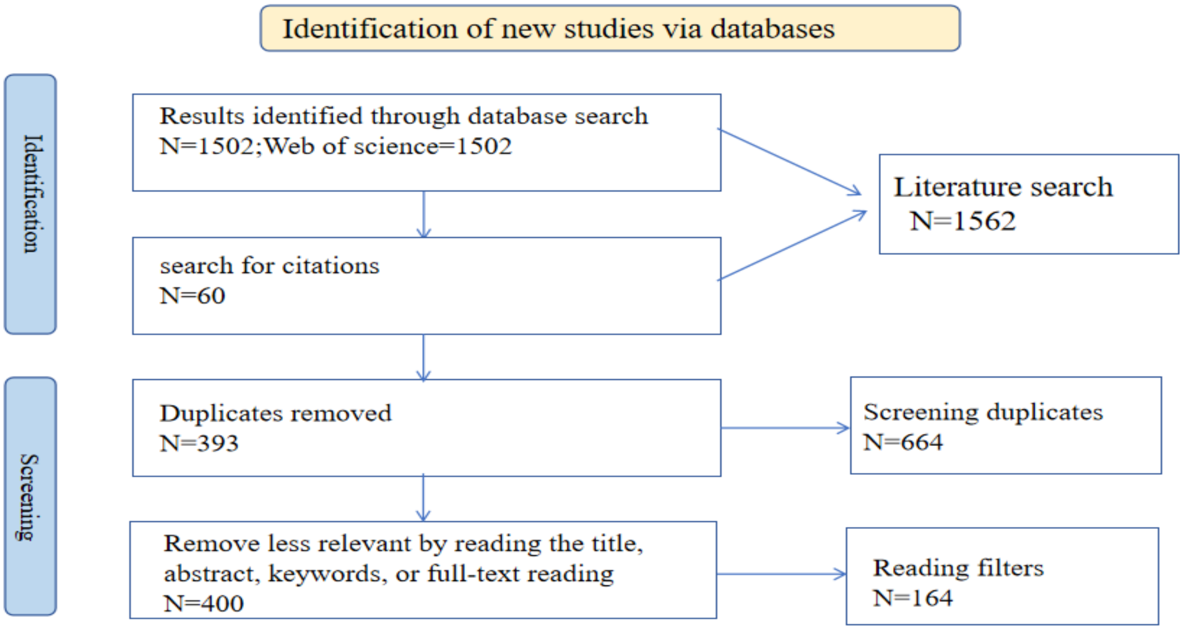


**Figure 1.** Data selection according to PRISMA template. Source: Created by authors.

There are three methodological stages in reviewing PRISMA standards: Section 2.1. Collection of relevant data; Section 2.2. Data selection; Section 2.3. Comprehensive analysis.

### *2.1. Collecting Relevant Data*

The review used two rounds of data selection workflow: an online database search and a citation search. The first search was on Web of Science, from which articles were identified using the selected search string (Assembly M&E OR Assembly MEP OR Assembly electromechanical OR Assembled electromechanical OR Assembly electromechanical system). From which articles were identified, duplicate records were eliminated, and to ensure that no articles were missed, 164 articles were screened by reading the titles and abstracts in reverse.

### *2.2. Data Selection*

Through the selected literature, this paper provides a systematic review from the perspective of the whole life cycle of assembled MEP systems, including five stages: planning and design, prefabrication and processing, installation and construction, operation and maintenance, and dismantling and reuse. Moreover, statistics were made according to the paper's year of publication (see Figure 2).

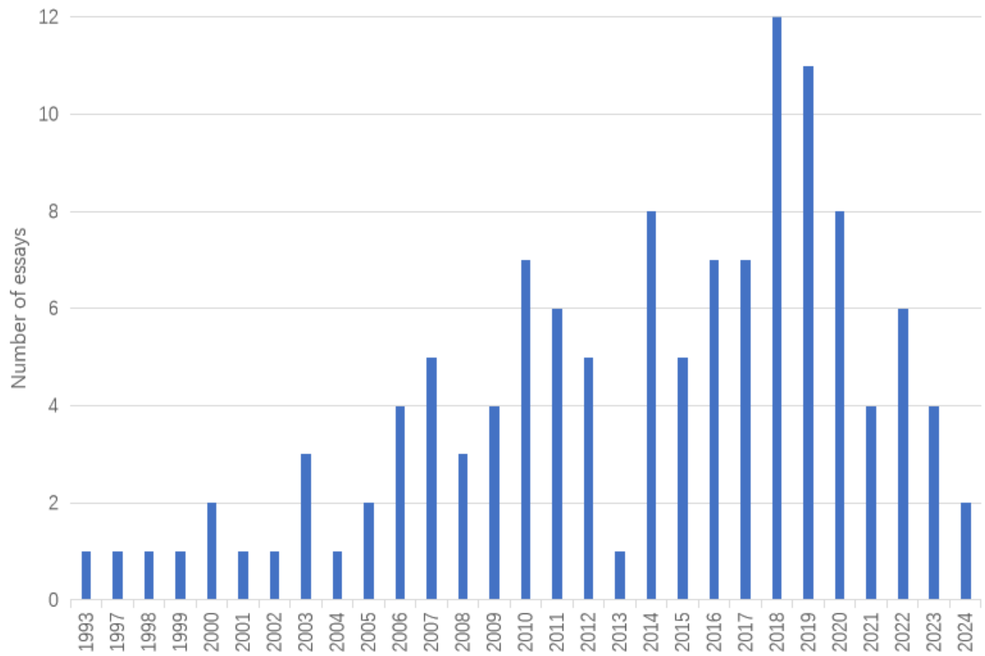


**Figure 2.** Number of papers: 1993–2024. Source: Created by authors.

### 2.3. Comprehensive Analysis

In order to address this issue of the future outlook of assembled M&E systems in China, the article identifies the research carried out by various scholars in each stage of the full life cycle and summarizes and discusses it through a descriptive analysis of the screened literature. In this regard, the article explains each life cycle stage by dividing it into stages.

## 3. Results Analysis

### 3.1. Full Life Cycle Stage Division

This paper divides assembled M&E systems into five stages: planning and design [8], prefabrication and processing [9], installation and construction [10], operation and maintenance [6], and dismantling and reuse [11], to fine-tune the study of the impact of assembled M&E systems on future development.

Planning and Design Stage: This stage determines the system requirements and design options. The planning and design ensure that the system can meet the desired requirements and objectives during installation and use.

Prefabrication and machining stage: In this stage, the components and parts of the electromechanical system are prefabricated and machined according to the design plan. By advancing some of the work to the factory, quality and efficiency can be improved, and the time and labor requirements during on-site construction can be reduced.

Installation construction stage: In this stage, prefabricated and processed components and parts are delivered to the site, assembled, and installed. By installing the prefabricated components on site, construction time and work risks can be reduced, and the quality and efficiency of the installation can be improved.

Operation and maintenance Stage: The M&E system is formally put into operation and undergoes routine operation and maintenance. Through regular maintenance and monitoring, the system's stable operation can be ensured, and possible faults and problems can be dealt with on time.

Dismantling and reuse stage: At the end of the system's life cycle, the electromechanical system needs to be dismantled and disposed of. Rational dismantling and reclamation can reduce the environmental impact, and the recovery and utilization of waste and resources can be maximized.

The five stages help manage and control the entire lifecycle of an assembled MEP system to ensure that it operates efficiently, reliably, and in harmony with the environment. With the five research priorities identified through the stages, this paper will refine the workflow further.

### *3.2. The Whole Life Cycle Stage Process of the Assembled MEP System*

It is crucial to clarify the implementation process of each stage, and the only way to find the keywords for future development is to detail the specific implementation process so that this section will study each stage of the whole life cycle in detail. The overall lifecycle workflow of the assembled electromechanical system begins with the owner and the design unit analyzing and completing the drawing design [8] and the prefabrication plant carrying out the drawing submission. The prefabrication plant prefabricates the components [12] and then transports them to the site for installation by on-site construction crews [13]; the system is delivered by the construction crews to the property owner and the equipment supplier for operation and maintenance [6], and finally recycled by the recycling unit and the new owner [11], as shown in Figure 3.

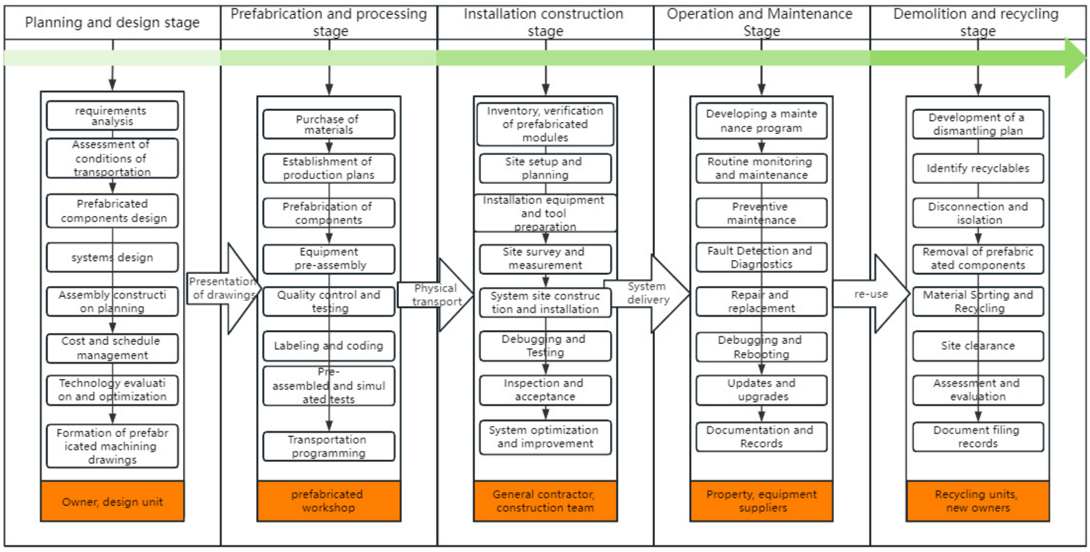


**Figure 3.** Full Life Cycle Flow Chart. Source: Created by authors.

Of course, for the development of assembly electromechanical, we not only need to look at the academic community for its research, but national policy guidance is also very critical. In this regard, this paper selects some representatives of domestic and foreign policies to elaborate further on national policy and academic research for integration.

### *3.3. Policy Overview*

The article analyzes the relationship between policies and assembled M&E systems by selecting representative policies at home and abroad to explore the impact of national policies on the development of assembled M&E systems.

#### 3.3.1. Foreign Policies

The assembled houses in western developed countries have developed to a relatively mature and perfect stage. The United States, Japan, Germany, France, Denmark, and the European Union are the most typical countries and regions. This chapter summarizes the policies and analyzes their national policies to assist China's assembly development. Assembly has been popularized in the United States since the 1970s, so it is necessary to study it. Its NFPA241 [14] stipulates the standards during construction, remodeling, or demolition. GSA (P100) has made mandatory requirements for design standards and performance standards [15], FEMP [16], and FBS [17]. ISO 23347 [18] has requirements for factory automation and energy. In addition, the U.S. Green Building Council [19], the American Institute of Architects [20], the American Institute of Steel Construction Release [21], the Modular Building Institute [22], and the American National Standards Institute [23] all provide instructions for structure, energy, and developing details. Japan's JIS [24] has also made strict regulations on precast concrete, and BL [25] has made certification standards and evaluation criteria for components. Germany's EnEv [26] has further requirements for energy-saving in buildings, and DIN EN 13369 [27] has standardized precast concrete component products. France's HQE [28], NF EN 13369 [29], and Denmark's BR18 [30] provide requirements for building permits, and DS/EN 13369 [31] provide specifications, essential performance criteria, and performance stability. The European Union's ED [32] and EPBD [33] have also contributed to its development. The red line in the figure represents when the policy was updated (see Figure 4). The abbreviated policy names are elaborated in the following figure (see Table 1).

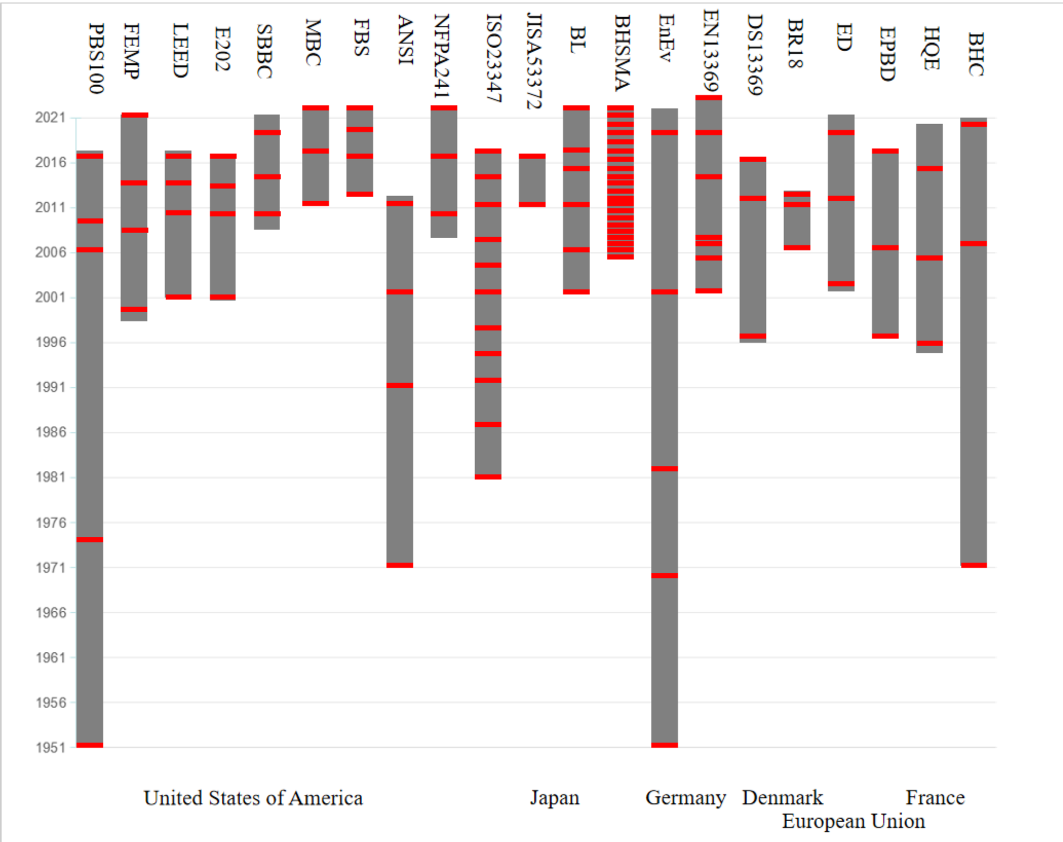


**Figure 4.** National representative policy statistics. Source: Created by authors.

**Table 1.** Explanation of the terms in the chart above.

| | |
|---|---|
| FEMP | Federal Energy Management Program |
| NFPA | National Fire Protection Association |
| E202 | AIAE202TM BIM Protocal Exhibit |
| SBBC | Code of Standard Practice for Steel Buildings and Bridges |
| MBC | Modular Building Codes |
| FBS | Factory-Built Structures Regulations |
| BHSMA | Building Height and Safety Measures Act |
| ED | Ecodesign Directive |
| EPBD | Energy Performance of Buildings Directive |
| HQE | High-Quality Environment |
| BHC | Building and Housing codes |

#### 3.3.2. Domestic Policies

The development of the industry and the promulgation of policies, as well as support, are closely related to policy, which often represents the direction of the industry as well as the degree of importance of the country. The following is a brief overview of China's policy.

It is not difficult to see from the documents continuously issued by the state that the state attaches importance to the development of assembly, and intelligent construction, in February 2016, the State Council issued the "CPC Central Committee and State Council on further strengthening the management of urban planning and construction of a number of opinions" put forward to vigorously develop the assembly of buildings [34]; in September 2016, the General Office of the State Council issued the "Guidance on the vigorously development of the assembly of buildings" [35], the document pointed out that it is necessary to coordinate mechanical and electrical equipment, and promote the integrated and integrated design of assembled buildings; in October 2016, Shanghai's 13th Five-Year Plan was promulgated [36], and during the implementation period, it encouraged the landing of projects with high prefabrication rates by continuously introducing matching policies for each stage of the whole life cycle, exceptional financial support, and policies such as the area bonus for the volume rate; in August 2020, the Ministry of Housing and Urban-Rural Development and other 13 departments jointly issued the Guiding Opinions on Promoting the Synergistic Development of Intelligent Construction and Building Industrialization [37], which clearly put forward the guiding ideology of promoting the synergistic development of intelligent construction and building industrialization; in March 2021, the 14th Five-Year Plan for National Development [38] pointed out that it is necessary to develop intelligent construction and accelerate the promotion of green and low-carbon development, and these policies show the country's determination to develop the assembled type, and also emphasize the traditional necessity and inevitability of switching to a new intelligent construction method.

##### Planning and Design Stage

In April 2013, the Ministry of Housing and Urban-Rural Development of the People's Republic of China issued the "Notice on the Issuance of the Twelfth Five-Year Plan for the Development of Green Buildings and Green Eco-city" [39], which proposes to complete the compilation of standards for coordinating the modularity of residential buildings and components as soon as possible, to promote the formation of industrialization and standardization systems, and to accelerate the construction of industrialized bases integrating design, production, and construction. And construction in one industrialized base construction. In January 2018, the Ministry of Housing and Urban-Rural Development released the national standard, "Evaluation Standard for Assembly Buildings" [40], significantly advancing the systematic assembly of assembly buildings. In April 2021, the "14th Five-Year Plan for New Infrastructure in Shanxi Province" [41] pointed out the need to guide the development of assembled In June 2022, the Chongqing Municipal Urban Renewal and Enhancement "14th Five-Year" Action Plan [42] proposed to actively promote the industrialization of construction, promote the integrated and standardized design of assembled buildings, accelerate the formation of standardized, modular, and universal parts and component supply systems, and promote the city's green and low-carbon transformation.

##### Prefabrication and Machining Stage

In January 2013, the Notice on Transmitting the Green Building Action Plan of the Ministry of Housing and Urban-Rural Development of the Development and Reform Commission [43] pointed out the need to accelerate the technology and efficiency of assembled components and to improve the level of industrialized construction integration; in February 2017, the State Council issued Opinions on Promoting the Continuous and Healthy Development of the Construction Industry [44] pointing out that it is necessary to promote innovation in the construction method and advocate modern construction methods; In March 2017, the Ministry of Housing and Construction issued the Notice on the Issuance of the 13th Five-Year Plan for the Development of Building Energy Saving and Green Buildings [45], which proposed to accelerate the construction of production bases for assembled components and to improve relevant policies, standards, and construction systems.

In December 2016, the State Council issued the Notice on the Comprehensive Work Program for Energy Conservation and Emission Reduction in the 13th Five-Year Plan [46], which proposed to implement green construction, promote energy-saving building materials, and implement assembly development. In July 2020, the Ministry of Housing and Construction and other seven departments issued the Action Program for the Creation of Green Buildings [47], which proposed to promote the assembly of construction methods and create an assembly system. Assembly construction methods create assembly building industry bases and improve the construction level.

Operation and Maintenance Stage

In November 2021, the Shanghai Assembly Building's "14th Five-Year Plan" [48] highlighted the need to deepen and improve the application level of building information technology, realize the optimization of operation and maintenance programs, promote the reform of storage and transportation, encourage the increase in automated assembly lines, and study the assembly construction plans.

Dismantling and Reuse Stage

The Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution of the Environment, issued by the Standing Committee of the National People's Congress in April 2020 [49], clearly states that it is necessary to promote the reduction of construction waste at the source and to establish a system for recycling and utilization of construction waste. The Ministry of Housing and Urban-Rural Development issued the Guiding Opinions on the Promotion of the Reduction of Construction Waste in May 2020 [50], which call for the promotion of technology for the reduction of construction waste and management innovation and realize the classification control and reuse of construction waste at construction sites. In May 2020, the Ministry of Housing and Urban-Rural Development issued the Guidance Manual for the Reduction of Construction Waste at Construction Sites [51], which requires construction units to prepare a unique plan for the reduction of construction waste, fully apply new technologies, materials, techniques, and equipment, and implement a unique plan for the reduction of construction waste. Waste minimization is a plan that effectively reduces construction waste emissions from construction sites.

Together, these policies and measures are driving the assembly of M&E systems in China. The government is continuously adjusting and improving the policy framework to adapt to changing market demands and technological innovations, creating a favorable environment for the sustainable development of the assembled M&E systems industry. The continued evolution of this process is expected to further promote the widespread use of assembled MEP systems technology in China to meet the challenges of urbanization and sustainable development.

### 3.4. Summary

By summarizing the government policies at home and abroad, it is easy to conclude that the rapid development of assembly electromechanical cannot be separated from the state's strong support. In summary, the United States and other countries in the field of assembly are in the leading position, which is closely related to the introduction of national policies and norms. In order to adapt to the development of the new era, China should introduce more detailed policies to regulate the market further and promote the development of assembly electromechanical. In order to explore the prospects of MEP systems in Chinese buildings further, the following article will discuss the perspective of the whole life cycle.

### *3.5. Keywords Analysis*

In order to further study the hotspots of electromechanical assembly in the last decade, keyword analysis is carried out through CiteSpace. The literature from 2010 to 2024 is selected from it. The output shows that there are a total of 268 keywords in the literature about assembly M&E. From the figure, we can also see that the research hotspots are concentrated in the four significant nodes of performance, design, fabrication, and films, which are closely followed by behavior, model, composites, and other keywords. These keywords all indicate the academic community for the future trend of assembly electromechanical exploration, and through the design, composites and other keywords are reflected in the future of assembly electromechanical in the whole life cycle of the various stages of the overall synergies as well as intelligent management (see Figure 5).

The research hotspots can already be derived from Figure 5. Next, this chapter will analyze the development of building MEP systems in China from the planning and design perspective, prefabrication and processing, installation and construction, operation and maintenance, and dismantling and recycling stages of the whole life cycle. Its achievements and issues at different stages are highlighted to provide insight into this key area's current status and future trends.

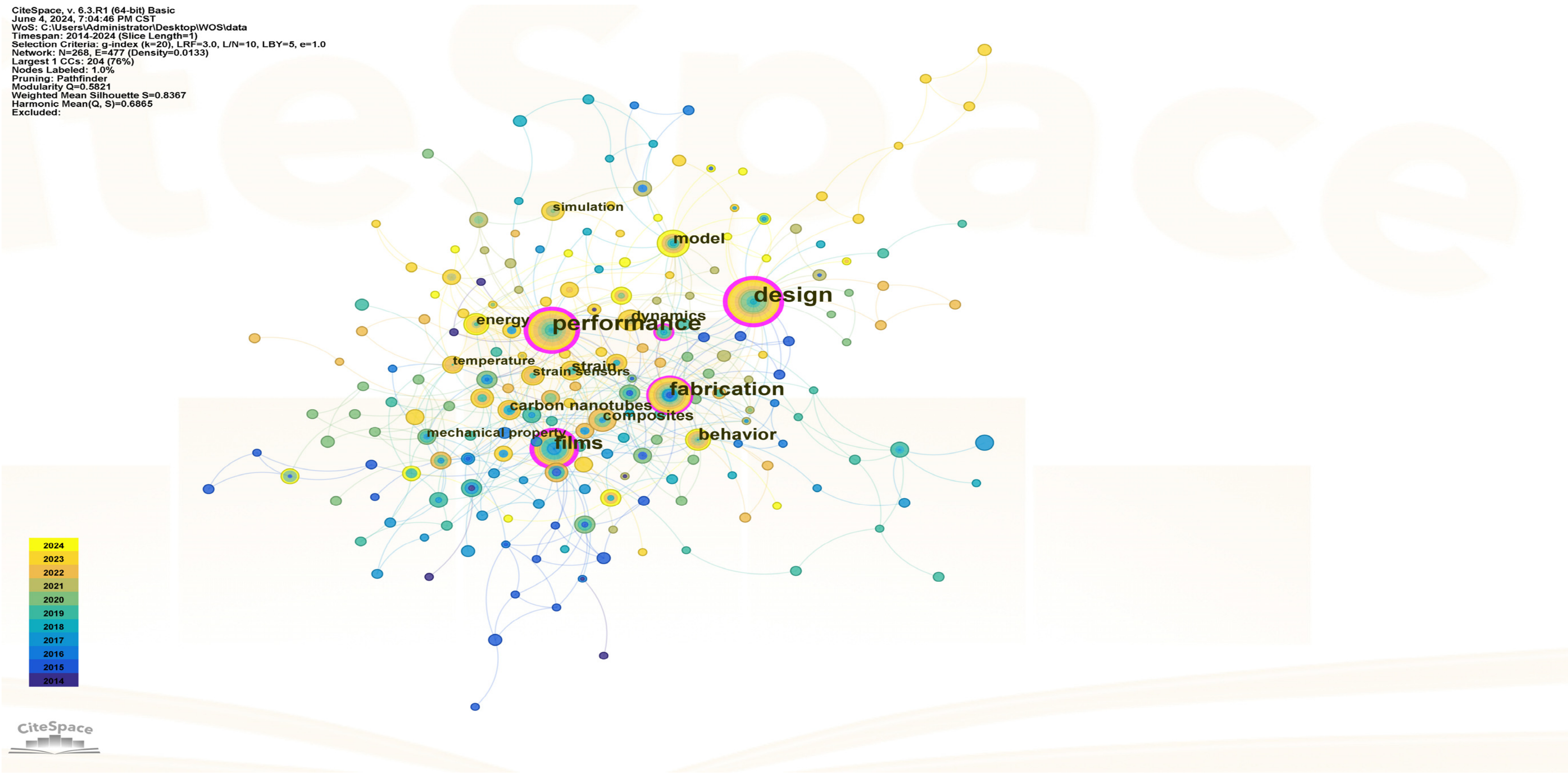


**Figure 5.** Recent assembly electromechanical research hotspot. Source: Created by authors.

### 3.6. Planning and Design Stage

At this stage, a series of complex issues are often faced. This section discusses and analyzes specifications, reserved space, design tools, design synergy, cost, environmental factors, safety, and comfort.

#### 3.6.1. Specific Analysis of the Planning and Design Stage

As the assembly process is not uniform across the country, there is a contradiction between standardization and customization, often with different standards between different provinces and cities and inconsistent customer demand for customization [52]. Therefore, inconsistent standards and specifications are a challenge. This requires projects to adhere to all applicable standards for consistency and compliance [53]. Therefore, designers should focus on the standardization of components at the design stage [54]. However, this task becomes more complex when multiple objectives, constraints, many pipe segments and their accessories, and changes in design requirements need to be considered [55]. In addition, space design is also a great challenge when planning and designing, and suitable access must be reserved for subsequent installation, maintenance, and other services. Crowded construction space can lead to low productivity [56], so it is essential to integrate space and construction projects. Creating a flexible schedule for space usage [57], applying 4D building information modeling solutions [58], proposing a new space planning framework [3], and developing a computational framework for optimizing the creation of piping spools [3]. to improve the performance of the MEP construction process. Another issue that has to be paid attention to is control in the design planning process. Thus, Fernanda S. Bataglin et al. [59] proposed a model for planning and controlling the delivery and assembly of engineering orders.

Additionally, a predictive model for prefabrication feasibility [60] found that prefabrication feasibility depends mainly on industry-related determinants. This informs the design of planning and control systems. Studies have shown that a system's optimal degree of modularity is closely related to module size and module division points [61], which requires careful planning and coordination between multiple parties in the planning and design. It is an informative and rigorous process, and the accuracy and timeliness of information transfer are critical. Collaboration among multiple stakeholders is also vital [53], so enhancing collaboration among all parties is a critical factor in problem-solving [62]. An integrated project delivery approach has been found to enable project participants to collaborate early in the lifecycle [63], and the development of a collaborative design platform using knowledge-based MEP information modeling and automated analysis improves collaborative design [64]. BIM/VDC (Virtual Design and Construction) is applied to install MEP components collaboratively [65]. The use of BIM technology promotes collaborative design [66]. It optimizes blueprints through automated fine-tuning [67], which can significantly reduce waste in the design, and also optimizes the design of MEP systems through MEP energy consumption analysis [67]. Ensure the project proceeds as planned and achieves the desired goals [53]. Cost issues have also been present in the planning and design processes, where cost and budget constraints are often an issue. Projects may be subject to tight budgetary constraints [68], which may compromise M&E system performance or sustainability [69]. As a result, Riley et al. [70] investigated the main factors affecting costs related to co-design practices for MEP systems. Also, insufficient consideration of environmental sustainability is an issue. With the advancement of time, it is required that projects' carbon emissions and environmental pollution be effectively controlled [71]. As a result, Samarasinghe et al. [61] proposed a broad framework for optimizing the construction of environmental protection systems to optimize the environmental impact. Finally, MEP systems are critical to the functionality of the building, so they must meet performance expectations in terms of comfort and safety. Design is critical for subsequent stages, and waste minimization design is a crucial strategy for early and effective construction waste reduction [72].

However, many project planning designs still lack sufficient attention to these factors summarized in this chapter, which can lead to adverse effects throughout the life cycle of the assembled MEP system.

#### 3.6.2. Summary

From the research results of many scholars, it is clear that the field has made much progress in the planning and design stages of assembled M&E systems. However, the literature of many research efforts devoted to this assembled MEP system has revealed that several issues and challenges still need to be solved in the planning and design stages of assembled MEP systems. These include inconsistencies in standards and codes, insufficient consideration of environmental sustainability, technology updating and integration issues, cost and budget constraints, and multi-stakeholder synergies. Many scholars have also made many efforts in this direction, but these technologies still need to be mature enough, and further exploration is needed. The key to solving these problems lies in enhancing the collaborative work in the planning and design stages, describing them as a project ecosystem [73], paying attention to the latest technologies, grasping the frontiers, and searching for innovative solutions under budget constraints.

The planning and design stage of the assembled MEP system ensures its efficiency and feasibility and lays the foundation for the prefabrication and machining stages. With the design drawings and models finalized, we now turn to the prefabrication machining stage of the assembled MEP, where prefabrication machining, carried out in a controlled environment according to stringent quality standards, will ensure that we can efficiently and accurately construct MEP modules that meet the design requirements.

### *3.7. Prefabrication Processing Stage*

The prefabrication and processing stages are critical to the quality and efficiency of subsequent M&E systems. This section explores the important influencing factors that limit the development of assembled M&E systems. It analyzes several factors that influence manufacturing standards, testing, decision-making, transportation, and new materials.

#### 3.7.1. Specific Analysis of the Prefabrication and Processing Stage

Assembled MEP projects are one-offs, which can lead to a lack of standardization throughout the project's life cycle. Product design details are highly variable [74], which may lead to non-uniformity of equipment dimensions and more significant problems of plant standardization and replicability. As a result, Connor et al. proposed a modular and standardized industrial plant design approach to solve this problem [75]. In addition, the replicability of the assembled M&E system is improved by focusing on the fabrication process of the pipe core [76]. Another area for improvement is that since the prefabrication is one piece, this leads to a high degree of difficulty in the inspection process after fabrication is complete. It has been shown that approximately 10% of construction rework costs are due to delays in detecting defects [77], which can lead to higher costs for prefabricated components. Therefore, automated techniques can be used to detect defects [78]. Quality management models can also be used to detect defects during pipe prefabrication using automated techniques such as photogrammetry and laser scanning [78], which can reduce the project's total cost by reducing manufacturing rework. Also, sensing technologies can be used for obstacle avoidance, productivity improvement, and material and equipment tracking [79]. BIM technology should also be introduced to monitor component prefabrication and pipe prefabrication [80]. By introducing these technologies, field defects will be significantly reduced, and the durability of components will be improved, resulting in cost savings and increased productivity [81].

Another point is that efficient communication and decision-making will significantly improve productivity. In this regard, MEP contractors should cooperate with manufacturing plants [55], and sequential coordination strategies are better than parallel strategies in coordination productivity [82]. In addition to efficient communication, it is also crucial for the optimal number of modules and system division points. As a result, an automated and efficient modularization algorithm can be used to determine the optimal number of modules and the system division point to ensure segmentation efficiency [61]. It has been shown that eliminating unnecessary framing methods in the upper part of the M&E system is most efficient when the coordination period is guaranteed, and adjusting the support spacing is also an economical design option [69]. Another critical factor limiting the development of assembled M&E systems, transportation, will have to be raised next. It has been shown that transportation is one of the factors limiting the development of prefabricated components [83], and the logistics of transportation [84] is a great challenge; heavy or large-sized M&E system components are very challenging to transport, and long-distance transportation or narrow and uneven roads can pose significant limitations. Prefabricated components should be as light as possible, as they sometimes need to be transported over long distances [85]. Therefore, embedded column connections can be used as an alternative to the traditional post-cast fixed steel load-bearing plates to reduce the weight and volume of the M&E system components to meet the transportation conditions [86]. Of course, the inclusion of BIM for on-site transportation management should also be considered [87]. Local policy documents should also be closely followed, as the impact of policies has a more significant influence on transportation logistics [88]. Another factor that affects the development of components is updating new materials. New technologies involving new materials have yet to receive a response from the community due to the lack of proper design guidelines. Therefore, the lack of evaluation criteria is likely the most critical deterrent to accepting new materials [89]. However, reading the literature, it is known that many materials developed by Manalo et al. may be used to develop modularization [90].

#### 3.7.2. Summary

Through the discussions and research of many scholars, it is easy to conclude that the prefabrication and processing stages of assembled electromechanical systems are complex and vital processes. The prefabrication stage mainly involves processing raw materials or semi-finished products into various components the system requires. The core of this stage is to improve efficiency under the premise of guaranteeing safety, ensuring the quality of prefabricated products, adopting new materials and methods to reduce costs, and improving the durability of the components. The accuracy and quality of the prefabricated components directly affect the smoothness of the subsequent installation and construction stages and the operation and maintenance stages, as well as the entire system's performance.

Compared to traditional building MEP construction, the fabrication of assembled MEP systems requires a more complex stage. However, off-site fabrication provides cheaper, safer, more sustainable, and higher-quality MEP system components [91].

Completing the high-precision prefabrication and machining stage marks the full readiness of all the assembled MEP modules. At this point, we will enter the critical installation and construction stage, relying on specialized construction teams and precise and error-free coordination mechanisms to integrate the prefabricated MEP modules into the building structure. Ensuring the integrity and functionality of the system is finally realized.

### *3.8. Installation Construction Stage*

The construction stage of assembly MEP installation is an essential part of the overall prefabricated building process, which involves the final assembly and interface coupling of MEP components and modules prefabricated at the factory and completed at the site. This section will analyze the factors that influence it, mainly regarding schedule planning, BIM application, optimum splitting point, safety, information utilization, and cost.

#### 3.8.1. Specific Analysis of the Installation Construction Stage

Studies have shown that assembly time accounts for about 20%~50% of the total production time, and assembly cost accounts for about 20%~30% of the total manufacturing cost [92]. As a result, there is a need for construction schedule planning for the entire installation construction process [93] and the introduction of tools that can significantly enhance worker efficiency. By enhancing the use of building information modeling (BIM) in the construction of mechanical and electrical engineering layouts [82], the visualization of BIM can effectively calculate the workload on-site [94]. Moreover, it can accurately find the specific points of problems and failures in the system, and it can effectively accelerate the progress of construction [53]. Invoking BIM technology can also effectively control the number of laborers and labor time, avoiding time delays and cost overruns.

Regarding human perception, Sweany et al. [95] found a statistically significant relationship between information format and task performance, with 2D atlases significantly inferior to 3DCAD models and 3D printing. Goodrum et al. [96] also investigated how the spatial cognition of pipefitters affects their performance in a scale model assembly task by showing that when supplemented with 3D displays, spatial participants with lower spatial cognition could maintain essentially the same efficient model assembly as participants with high spatial cognition. Therefore, this can be accomplished by attaching information to the product using one of the existing ID methods [97]. Another central issue is safe construction; the use of mechanical lifting aids can significantly reduce the risk of injuring workers by manual labor [98], and combining modular assembly with delay strategies can also reduce the risk of field operations involving injury risks such as cutting and drilling in MEP construction [98].

The following aspect of cost reduction and efficiency is that the constructor should rationalize the flow segments to improve the installation speed [54]. New algorithms are introduced to determine the optimal number of modules and system division points to minimize the installation cost [61]. Modularization provides more rapid on-site assembly than on-site construction [55]. Reducing construction time and intensive workloads is one of the economic benefits of prefabricated buildings [81]. Studies have shown that labor costs usually account for a large share of the overall project M&E costs [98]. In this regard, further research is carried out by investigating the above-identified problems to achieve cost reduction and efficiency [99].

#### 3.8.2. Summary

It is concluded from extensive reading of the literature that the research and application of assembled M&E systems can significantly improve the efficiency of installation and construction. The assembled M&E system can pursue higher quality and cost-effectiveness by improving new methods and materials to realize cost reduction and efficiency. Moreover, the safety of workers is always a priority, following the concept of being people-oriented. In conclusion, the research and application of assembled M&E systems in the installation and construction stages have significantly contributed to the architectural and engineering fields regarding risk reduction, efficiency, cost savings, flexibility, and customizability. Its ability to drive the industry in a more efficient and sustainable direction.

After the construction team has installed all the prefabricated modules into the building with precision and accuracy, the MEP system has been perfected, and all the components and units have been integrated to form a coherent whole. This leads to the next stage of operation and maintenance, where more emphasis is placed on the process of monitoring and managing the MEP system.

### *3.9. Operation and Maintenance Stage*

The operation and maintenance stage of the assembled MEP is a vital part of the whole life cycle to ensure its long-term stable operation and reach the expected service life. This section will analyze and discuss the O&M (operation and maintenance) stage of assembled MEP systems, mainly from the aspects of importance, BIM, algorithms, component life planning, and inspection.

#### 3.9.1. Specific Analysis of the Operation and Maintenance Stage

The importance of building maintenance is emphasized worldwide, and the proportion of systems in buildings is increasing [100], and the maintenance cost is a higher percentage of the life cycle cost of buildings [101]. A report from the National Institute of Standards and Technology shows that the U.S. construction industry wastes about $15.8 billion annually, of which about $10.6 billion occurs in the O&M stage [102]. Their O&M costs represent a significant percentage of the total project [65].

Effective maintenance of building performance can minimize adverse impacts, and from this perspective, it is essential to establish a proper maintenance plan for O&M [103]. One of the reasons for the low level of intelligence in the management of M&E systems during the O&M stage is that M&E management needs to take full advantage of the new technologies that have emerged with the development of information technology. For example, building information modeling technology [6]. In this regard, researchers should embark on introducing new technologies, and studies have shown that three-dimensional visualization is helpful in property management [104]. The development of BIM models provides an intuitive view of the system's operational status for MEP operations, and the efficiency of maintenance coordination is improved [64], as is the ability to detect possible problems [70]. BIM ensures the sustainability of buildings by managing various information in a unified manner [105]. Researchers have developed a multi-scale BIM-based facility management system for M&E works and applied it intensively in real-world, large-scale airport terminal M&E works [106], where practical examples have proved its feasibility.

Regarding algorithms and information recognition in the O&M stage, methods of automatically constructing logical chains, equipment identification, and grouping mechanisms are used. As well as algorithms for generating geographic information system maps based on building information during the delivery of MEP management in the O&M stage [6], the final information generated in the design and construction stages is standardized and delivered to the O&M stage [107]. Two-dimensional barcodes are used to identify and locate specific equipment for routine maintenance of the M&E system and its subsystems to ensure proper equipment operation.

Another essential factor to be considered in the O&M stage is the service life [108], which should consider the different usage scenarios of real users [109]. In reality, various parameters, such as quality and user patterns, affect the lifetime of MEP components. This poses a risk to the building maintenance program because the replacement of components occurs at different times [110]. Therefore, life planning of MEP system components can improve the accuracy of maintenance programs [111]. Estimating the lifetime of the electromechanical components of various assembled M&E systems [112] is essential for building maintenance planning of assembled M&E systems [113].

In terms of inspection and maintenance in the operation and maintenance stage, it is difficult to find the failure points and solve the problems because the M&E systems are mostly installed and hidden in the interior of the building. New technologies are needed to adapt to the development, and new methods of monitoring structural health using laser scanning can be used [114]. Subsequent studies have confirmed the usefulness and effectiveness of these techniques for quality control [115] and damage detection [116], as well as for monitoring thermal conditions using wireless sensor networks [117].

Proposing new models for the O&M stage is also a good option. Yu et al. [118] created a set of equipment management classes, essentially a prototype of an O&M information description standard. ElAmmari [104] investigated an IFC-based property management model constructed by sharing IFC standard-generated design and construction information through an extensible markup language in O&M management. The National Institute of Building Sciences established a building operations information exchange to support operations and maintenance [119].

#### 3.9.2. Summary

In summary, during the operation and maintenance stage of an assembled M&E system, it is necessary to regularly inspect and maintain the components, monitor operational data, and troubleshoot. At the same time, maintenance and continuous improvement are necessary to ensure the system's stable operation and efficiency. Its primary research lies in cloud computing and IoT computing, including BIM, algorithms, laser detection, chip processing, and other dimensions. Realize the real-time monitoring and prediction of the operating status of the equipment, discover potential failures, and take measures in advance to reduce the system's maintenance cost and improve the equipment's reliability and stability.

The assembled electromechanical system has better energy performance in the operation stage compared with traditional construction [120], and modern technology provides a solid technical guarantee for operation and maintenance to realize stable operation and satisfactory maintenance. Now, with the development of the life cycle and the adaptation to the progress of the times and the iteration of technology, we need to enter the next stage, the dismantling and reuse stage. This stage lies in the efficient deconstruction of electromechanical system components and the rational manufacture of economic benefits according to the economic cycle while following the principle of carbon reduction to reduce carbon emissions and waste of resources reasonably.

### *3.10. Dismantling and Recycling Stage*

The deconstruction and recycling stage of assembled M&E is an integral part of the environmental and sustainability strategy. This strategy aims to maximize the use of existing materials and reduce the environmental impact through effective deconstruction and resource recovery when the equipment reaches the end of its service life. This section will explore and investigate the following essential aspects: deconstruction methods, data retrieval, and economics.

#### 3.10.1. Specific Analysis of the Dismantling and Recycling Stage

Carbon and energy, resource efficiency, recycling, construction waste, and waste management of materials such as piping used in MEP construction [121] are hot topics of current research [120]. Moreover, from a life cycle perspective, the construction industry is responsible for consuming large amounts of natural resources and producing landfill waste globally [122]. The current assembled construction waste is disposed of in landfills [123]. In terms of recycling, there is an urgent need in the new era to accelerate the research and development of building demolition planning methods to utilize the residual utility and value of today's colossal building stock [124].

The MEP project includes more than ten subsystems, such as HVAC, automatic control, and water supply and drainage. Each system is a complex combination of multiple components, such as equipment, piping, and wiring [106], so research on dismantling and reuse is necessary. Reusing assembled building components has been identified as a method to maximize the utility and value of the product [125]. Therefore, it must be emphasized in the dismantling and recycling stages.

However, problems are encountered in dismantling and utilizing recycling, such as detachability, recyclability, and deconstruction methods. In this regard, it was summarized by reading the literature that the LeanDfD method and software tools can be used to quantitatively assess the disassemblability and recyclability of electromechanical products [126]. Zeng and Li discussed and summarized the recyclability of various end-of-life electrical and electronic equipment types, including individual components and complete products [127]. However, the recovery of end-of-life products from extensive existing building inventories is hampered by the lack of integration of deconstruction methods, recycling, and demolition [128]. For this reason, selective demolition planning has been identified as a promising alternative to effectively address the recovery of end-of-life products from buildings [129]. Selective demolition planning, the sequence of steps to remove a target building component, is critical to the building component reuse process [130]. Research has focused on the technical assessment of the deconstructability of assembled structures to improve reuse [131]. However, current information models do not contain the necessary information to support deconstruction planning activities such as selective demolition [132]. Therefore, a classification of the information required for demolition modeling was developed [133], and BIM technology has become a critical system to support the construction and deconstruction planning processes [134] This technology enables accurate information with a powerful graphical interface. Although BIM has proven to be an effective tool for managing construction projects [133], current information models must support essential project activities. The main reasons for this are the need for more appropriate levels of detail in parametric disassembly models that define the correct physical interfaces between building components [130] and efficient methods for automatically determining the appropriate disassembly parameters from high-quality information models [135]. The main current difficulty lies in acquiring the parameters underlying the creation of accurate disassembly models [136], which remain elusive [137]. In this regard, the visual programming language of BIM can be an effective method for developing customized software solutions for the construction industry [129].

Further, an academic developed a first-of-its-kind BIM-based sequential building demolition planning method for selective demolition of buildings in 2018 [138]. This method was extended to multi-objective selective demolition planning in a subsequent study. A new building selective deconstruction planning method [139] was developed by improving their method by adding deconstruction methods for each building component [135]. Denis et al. [140] also proposed an alternative optimization method for building selective demolition planning by using network analysis, and their method was called disassembly network analysis, a selective hybrid demolition sequence planning method [141]. In addition, Wan and Krishna Gonnuru proposed a fuzzy logic model to solve the optimal recovery value estimation and demolition depth using a genetic algorithm [142]. Finally, Zhou et al. [143] extensively reviewed recent developments and future trends in manufacturing product disassembly planning. They examined the characteristics of different methods and summarized three aspects of the disassembly approach: disassembly modeling and planning methods.

With the development of the times, the disassembly information can be determined automatically by the volumetric and geometric analysis of cad-based disassembly models of finished products [144]. The disassembly sequence can be planned to extract defective parts [145] better. However, the disassembly sequence planning still needs to be more efficient due to incomplete information between assemblies and subassemblies [146]. Therefore, disassembly planning still requires manual intervention to determine the interrelationships between components [129]. Therefore, a new framework for the selective disassembly of buildings based on a disassembly graph model was developed [130]. However, the critical topological interrelationships of the building components are still inseparable from manual intervention, which can lead to reduced efficiency [129]. The new technology of MOC prefabrication of piping systems using threaded couplings, flange couplings, or grooved couplings holds incredible promise for the future, as the piping components connected through these three approaches are removable [55]. Some can be dismantled using modern automated dismantling [147], including mechanical shredding and automatic separation of raw materials [148].

Another critical issue in dismantling and recycling is the exchange of data between manufacturers and dismantling and recycling plants [149]. For this problem, storing the material content information in a code is possible by describing the problem of direct information exchange between the manufacturer and the dismantling plant regarding the material content [97]. Then, it can be used in the dismantling stage for recycling. RFID (Radio Frequency Identification) and Global Positioning Systems in solid waste management can also be considered [150], and RFID systems can help with collection and sorting [151]. The data are sent to the dismantling or remanufacturing plant via the Internet [152]. After retrieving this data in real-time during the dismantling process, there is an option to use an automated decision-making system to decide what to do with the components [153].

Analyzing renewable use through the cost aspect, we learned that the use of recycled components not only produces fewer carbon emissions than the use of new components when the transportation distance is less than 1800 km but also has a lower economic cost [154]. The life-cycle environmental and economic benefits of reusing structural components of assembled electromechanical systems were demonstrated [155].

#### 3.10.2. Summary

To summarize, in the disassembly stage, the necessary information is needed to include what kind of raw materials, what kind of hazardous substances, and the correct and effective recycling sequence [156]. Some hazardous substances [157] have to be separated; otherwise, they may contaminate other raw materials obtained in disassembly, and the removal of hazardous substances is required by law [157]. To better connect the whole life cycle, disassembly and recycling should be emphasized at the planning and design stages for the use of the whole process of data. As the last stage of the whole life cycle, it must be paid great attention to promote the perfect closure of the whole life cycle and to realize the reduction of costs and efficiency, reduce carbon emissions, and increase the utilization of resources.

## 4. Discussion and Analysis

### *4.1. Differences between Assembled M&E Systems and Conventional M&E Systems*

In the planning and design stage, by comparing the construction methods of traditional M&E, it is not difficult to conclude the advantages and shortcomings of the assembly M&E system because of the one-piece design, so it is necessary to make an excellent and detailed decision at this stage to satisfy each other to meet the matching and avoid problems such as inconsistency in the diameter of the pipe orifices. Conventional MEP system design offers a higher degree of flexibility, and design changes can be made more efficiently during the construction process, but this is because it is this flexibility that can cause instability in the MEP components. Compared to traditional MEP systems, assembly MEP systems can solve problems in advance, such as space conflict and installation sequence, better control the design and construction costs, and improve project information interoperability. The addition of BIM allows the stages to have better coordination and coherence.

In the prefabrication stage, the differences between assembly MEP systems and traditional MEP systems are mainly reflected in the component manufacturing environment, the level of customization, and component transportation. The assembly M&E system can be uniformly pressed in the factory. In contrast, the traditional M&E system mainly relies on on-site manufacturing, and the assembly M&E system can be customized according to the drawings with high-precision management. In contrast, the traditional M&E system relies more on on-site installation. However, the transportation of assembled M&E systems is relatively more complex, and it must be ensured that the finished prefabricated components arrive safely at the site. The main advantages of assembled M&E systems over traditional M&E systems are improved efficiency, higher quality control, a reduction of on-site processing safety risks, and the elimination of various on-site instability factors.

In the installation and construction stage, by comparing the installation of traditional M&E systems, it is easy to realize that in traditional M&E system installation, almost all the work is carried out on site. This involves cutting and assembling pipes, wires, ducts, and other system components on-site, which is often inefficient, and the working environment on-site is challenging to control. The safety and quality of construction may, therefore, be compromised. On the other hand, assembly MEP systems take a more convenient approach, featuring prefabricated and pre-assembled components of critical systems at a prefabricated manufacturing facility. This increases construction efficiency while improving the level of quality control. Since a significant amount of the work is conducted off-site, there is less disruption on-site, and the construction cycle is consequently shorter. Using assembly systems also reduces material waste on site and improves overall environmental sustainability. With a more standardized work process and lower risk, assembly MEP systems allow for better construction cost and time forecasting.

In the operations and maintenance stage, the main points of difference between the operations stage of an assembled MEP system and a traditional MEP system are modularity and replaceability. Assembled MEPs can remove a single faulty module, but traditional MEPs are usually fixed-mounted and often require the removal of the entire piece. The overall maintenance costs are higher, and because assembled MEP systems are designed with prefabricated, standardized modules, the costs of operations and repairs are lower. Maintenance is more time-sensitive, and prefabricated modules allow for quick installation, thus reducing the downtime of the M&E system.

Next, compare the difference between the assembled M&E system and the traditional M&E system in dismantling and reuse. The assembled M&E system is more advantageous in dismantling compared to the traditional building system; the assembled M&E system is a more concise and orderly dismantling process and easy to disassemble due to its modularity, while the traditional M&E system is usually fixed and mixed in the building structure, so the dismantling process is cumbersome. The cost of stripping is high, and the utilization rate is low. With a high reuse rate, the undamaged modules of assembled MEP systems can be directly used in the next system. In contrast, traditional MEP systems must be completely dismantled and rebuilt. The labor cost and time required for dismantling and dismantling the difficulty of assembling M&E systems are relatively low. Taken together, assembled M&E systems have more excellent value in terms of environmental benefits, lower cost of economic benefits through the use of materials, more leading time benefits, and significantly improved flexibility in dismantling and reusing.

### 4.2. Challenges and Prospects

In some countries, prefabrication is often described as a potential solution in the sustainable building process and in combination with the circular economy [158]. However, the downturn of the construction industry in the last two years has caused the industry to become marginally profitable, even with vicious competition. The main factors limiting the development of assembly M&E are that the industry is in a non-standardized situation, the process preparation time is too long, the factory labor productivity is low, the quotation reference is not uniform, the factory business is not saturated, the cost of the digital factory is too high, the factory mechanization is low, there is a lack of core competitiveness, the cost of the full-time installation team is too high, and the competition is high. To address these challenges. In September 2023, leading Chinese industry players co-organized an online forum conference with a semi-structured live interview on-site. The conference centered on the prospects of assembly M&E in China, and the participants consisted of seventeen organizations, including China Railway Construction Corporation, China Construction Fourth Engineering Bureau Corporation, and Chongqing University. The conference on the development of assembled M&E was discussed intensely, and a semi-structured on-site interview was conducted with the participants on the spot. The conference mentioned that because the current market for assembled M&E systems as a whole is showing a contraction and the industry is in a non-standardized state, there are no standards for the design of assembled plant rooms, no standard quotas, and no unified atlases and process standards. This can easily lead to process preparation time being too long, factory labor productivity needing higher, the offer needing a reference, and the overall low.

In this regard, the conference advocated using information and technology to achieve customer-centric, comprehensive cost reduction and efficiency. Implementing design sharing, factory sharing, installation team sharing, a unified standard process, platform management, and pooling industry resources reduces design costs. Integrate design, business, construction, and factory resources to form a national group or alliance.

Of the participants in the meeting, 14 units of representatives expressed support, accounting for 82%. There are three units with different opinions, accounting for 18%.

Supporters believe that the formation of a national alliance can give full play to the advantages of each region, go to resource integration, and, through the sharing model, be realized with the university for cooperation in design, with the surrounding factories for integration of production, and with the intelligent equipment manufacturers. Secondly, it will be partially modularized, and only standardized parameters must be inputted to realize the drawing. Furthermore, through the sharing mode, it realizes the production of assembled machine rooms, boiler rooms, chemical enterprises, and other end equipment. The sharing mode can highlight the advantages of assembly electromechanical, forming an industrial standardization process, integrating materials and tools and other measured costs, and standardizing prices; these will be essential to future development. Finally, the development of assembly electromechanical is in line with the requirements of the national dual-carbon economy; forming a national alliance is more conducive to attracting the government's attention.

Of course, some participants put forward different opinions. A prefabricated assembly machine room in the current market is not a necessary choice, belongs to something other than the necessary part of the non-standardized, and is easier to respond to the scene's needs flexibly. Another critical point is that the market demand for assembled rooms and standards could be more consistent, so it is unlikely to make all of them uniform and standardized. It should focus on the modularity of the equipment to achieve cost reduction and efficiency.

In short, through the shared design, shared factory, and shared installation mode to promote the development of assembly electromechanical, this mode can significantly reduce the operating costs of each family and unified standardized design standards. Reduce the pressure of long-distance transportation of prefabricated components. Flexible mobilization of the installation team will improve the quality of workers and reduce the cost of the installation team problem. However, it is also necessary to consider the market and its situation carefully, according to its actual application scenarios, to make the equipment modular rather than the whole room or system, increasing its flexibility. Finally, the assembly mode is in line with the country's dual-carbon economy needs, and the government should seek more support.

## 5. Conclusions

### *5.1. Summary and Contribution*

This paper reviews the existing research on assembly M&E, summarizes the existing research results of each phase by going through the whole life cycle perspective, and provides suggestions to overcome the problems of inconsistent standards and untraceability of the current assembly M&E system throughout its life cycle. It also provides suggestions for the future prospects of the assembly model for building MEP systems in China based on the summaries of industry conferences.

In summary, this paper is innovative in terms of methodology and content in terms of its contribution to knowledge, and there is little literature at home and abroad that provides a comprehensive review of the entire process of assembling M&E systems. In this regard, this paper provides a reference for subsequent research by scholars. In addition, by dividing the whole life cycle of the assembly M&E system, which is a novel way of division in the field of assembly M&E systems, the whole process can be comprehensively controlled, avoiding omission and repetition. This approach is better able to capture the key points of the problem and ensure its overall integrity. Second, in the data collection stage, a few articles summarize the policy in stages. This paper takes full account of the impact of the policy on practice and analyzes it. In practice, summarizing the problems and solutions at each stage and citing summaries from actual industry semi-structured interview sessions, provides some contributions to the development of the assembly M&E field in the future as well as China's implementation of advancing the assembly model for building M&E systems, which can be extended to other fields.

### 5.2. Outlook and Shortcomings

According to the article overview, although assembly MEP systems are now facing a series of problems, such as high cost and difficult coordination, it is not difficult to conclude that the up-front investment cost of the assembled M&E system will gradually amortize over time, which will in turn improve its cost-effectiveness. The future model of assembled M&E systems will also be a development process involving a combination of technological innovation, industry collaboration, policy support, and market demand. However, this paper also has some shortcomings. First of all, in terms of data collection and processing, this paper only collects some of the representative domestic and international policies on assembly electromechanical systems, which is not complete, so the subsequent research should focus on considering this point. Secondly, the article did not pay special attention to the technical ability of the personnel; different management teams and technical levels will have a huge impact on the cost and installation effect. Therefore, subsequent research should focus on this point as well. Finally, the paper is less critical of the thesis, and subsequent research should consider analyzing this in depth.

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