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Development Path of Construction Industry Internet Platform: An AHP–TOPSIS Integrated Approach

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Abstract: The Internet-based platform in the construction industry is a carrier for integrated construction information, which positively contributes to the development of smart construction sites (SCS). However, the lack of relevant research results in the ambiguous definition of the construction industry Internet platform. Meanwhile, the current development path of these platforms is also confusing. For this reason, this research first concludes on the main features of Internet-based platforms in the construction industry and puts forward a clear definition. Secondly, a large quantity of literature is overviewed to identify branches of Internet-based platforms as comprehensively as possible. Then, 26 platforms are sorted and classified according to different construction phases. Based on the analytic hierarchy process, an AHP–TOPSIS model, a decision-making method frequently used in the engineering industry, is established with dimensions of technology, demand, policy, and standards. Eventually, the priority of the development of the Internet platform of each segment is sorted, thereby forming the three-stage development path of the construction industry Internet platform, namely Foundation Construction Stage (Platform 1.0), Function Developing Stage (Platform 2.0), Platform Integration Stage (Platform 3.0), and analyzing the characteristics of each development stage. This research opened a clear path for developing Internet-based platforms and providing a basis for formulating development policies for these platforms in the construction industry. With the limitation of an incomprehensive summary of evaluation criteria and platform branches, a better-designed evaluation with more experts in various positions should be conducted in future further research.

Keywords: construction industry Internet platform; Internet-based platforms; smart construction; AHP; TOPSIS

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1. Introduction

Platforms have been regarded as a paradigm for managing new product development and innovation [1]. In this era, platforms, especially those based on the Internet, tend to spring out in industries whose development is accelerating, requiring media to integrate data information, judge current situations, and help make decisions. In other words, Internet-based platforms are a modern management tool for developing industries [2]. In the construction industry, the demand for the comprehensive performance of construction products is constantly increasing. Due to the obvious advantages of information technology, it is an inevitable trend to improve traditional management approaches to enhance the competitiveness of the construction industry [3]. To realize the conception of lean construction, intelligent technologies including BIM, 5G, blockchain, artificial intelligence, 3D printing, Internet of Things (IoT), big data, cloud computing, etc., have been utilized in smart construction sites (SCS) [4]. Hence, Internet-based platforms are a new-era product that integrate these intelligent technologies and evolve into a powerful management tool. It is of significance to conduct more in-depth studies on Internet-based platforms.

To promote the development of smart construction, many countries have introduced the conception of intelligent development in the construction industry accordingly, which is connected closely to Internet-based platforms. To be specific, Japan's rubric of Society 5.0 construction policy is linked with networks and regards the introduction of robots and the promotion of AI applications as strategic goals for future development [5]. The rebuilding infrastructure in the United States indicates AI and new materials as the new direction for the promotion of the construction industry [3]. The vision of digital-enabled modular construction in the United Kingdom highlights smart construction and the priority of digital design [3,6]. To follow this new trend, China has also issued guidance related to the synergistic development of intelligent construction and building industrialization as the key design document in this field [7]. According to the documents issued by the Chinese government, Internet-based platforms rank first among the five key areas for the development of smart construction, followed by digital integrated design, construction robots, component production lines, and SCS. Therefore, the development path of the Internet platform for the construction industry deserves concentration.

As is described, the Internet platform is an important tool to realize the collaborative work of the whole construction industry chain. However, there are few relevant theoretical studies at this stage and the existing studies only make advocacy suggestions based on the aforementioned policy documents. As a result, there is a shortage of research on the specific content of these Internet-based platforms. Naturally, the current development path of the construction industry Internet platform is still ambiguous. This paper is aimed at solving these two problems.

To address the research gaps and reach the target, this study intends to add a clear definition of the construction industry Internet platform and to explore the development path. To be specific, a systematic review of the literature is conducted to conclude the main factors of Internet platforms and to identify existing branches of platforms or those eager to be established. Meanwhile, a synthetic decision-making method, the AHP–TOPSIS method, was introduced to weight the evaluation standard of these platforms and to rank the listed platforms in aspects of weighted criteria. Section 2 presents the comprehensive literature review, which penetrates all aspects of the construction industry with the intention of a complete summary of Internet platforms in the construction industry and classifying them in the perspective of different phases. Section 3 describes the methodology and framework applied in this study. In this section, the AHP model is established for analyzing main criteria and TOPSIS is to provide an effective evaluation method. Section 4 illustrates the process of data collection by using a 7-point Likert-type questionnaire. The results of the proposing method are also computed in this section. Section 5 provides a discussion of the results which clarifies the development path of Internet platforms in the construction industry. Last, Section 6 gives a conclusion of this research.

2. Literature Review

2.1. Critical Features of the Construction Industry Internet Platform

Construction industry Internet platforms are always equipped with digital devices that help store and analyze data collected and transferred by IoT. These platforms make the on-site data connectable and visible. Chang et al., quantified the efficiency of IoT technologies in safety management and accident prevention, which verified the meaning of the investments in IoT–technologies and the establishment of related platforms [8]. John et al., explained the value of IoT technologies in enabling real-time monitoring systems for the prediction of early-age compressive strength of concrete [9]. Wang et al., proposed an interactive and immersive process-level digital twin (I2PL-DT) system in virtual reality (VR) to facilitate Human–Robot construction work [10].

Resulting from a large amount of information stored in platforms, Big Data is showing its value in deep data mining and analysis. Zhang et al., introduced a scalable cyber-infrastructure platform for diagnostic assistance and prognostic decision making [11]. Inti et al., put forward the Data Envelopment Analysis (DEA)-based preference aggregation method to improve the group decision model [12]. Chang et al., proposed a Bayesian inference-based method to analyze collected historical data and dynamic data, forming a decision–support approach for construction equipment acquisition and disposal [13]. All these cases demonstrate its capabilities in catering to clients' requirements and helping decision making.

Moreover, the Internet-based platforms can validly dispatch resources, capital, and devices for comprehensive information from all aspects. Siu explored the best way to determine a resource-constrained schedule and an under-time-dependent resource constraint through the Zero-One programming approach [14]. Ashuri and Tavakolan developed a shuffled frog-leaping model to integrate Time–Cost–Resource constraints and to optimize the distribution and supply of various resources [15]. Karaguzel et al., presented an open computing infrastructure, Virtual Information Fabric Infrastructure (VIFI) to complement conventional datacentric sharing strategies and support building energy simulations [16].

Taking advantage of the past cases and the analyzed data information, Internet platforms can offer construction experience libraries covering all kinds of knowledge, tools, and models, then update them constantly. In this area, Y.Rezgui argued that an effective solution to information and knowledge management (KM) needs of practitioners in the construction industry can be found in the provision of an adapted knowledge environment that makes use of user profiling and document summarization techniques based on information retrieval sciences [17].

Digital delivery methods are conducted to make delivery easier. R. Chacón et al., depicted a set of virtual reality (VR) and augmented reality (AR) applications conceived for experimental tests of beams, columns, and frames, accelerating the design and production of components [18]. In this way, Internet-based platforms promote collaborative design, productivity, and services.

By summarizing the current situation and recent applications, the construction industry Internet platform can be defined as an effective management medium, which contains six main features: data informatization, big data analysis, resource integration, knowledge informatization, digital delivery, and network cooperation. Construction industry Internet platforms are a new combination of information communication technology and modern construction technology, which are important carriers to facilitate digital and smart construction. Through a comprehensive integration of man, machine, material, method, and environment these platforms construct a new manufacturing and service system covering the whole construction process. The concept map of the construction industry Internet platform is shown in Figure 1.

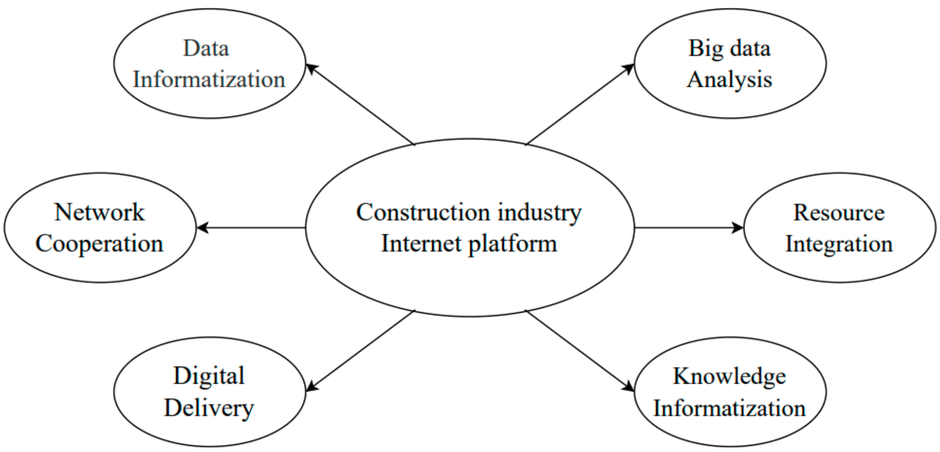

Figure 1. Main features of the construction industry Internet platform.

2.2. Platforms in the Construction Industry

2.2.1. Platforms in Topographic Reconnaissance and Design Phase

Although the research for Internet-based platforms is still ambiguous, quantities of platforms have been established and put into practice. Topographic reconnaissance starts at the beginning of construction projects, which lays the foundation for successful construction. Liu et al., adopted an information interaction platform of geo-drilling technology, which can store and share information from geography surveys and thereby realize the computer-aided design and intelligent geological management [19]. Tang and Burcu proposed that laser scanners can facilitate the digitalization of bridge surveying by collecting dense 3D point clouds that real-time upload surveying results [20]. To improve the efficiency of design, D. Utkucu et al., used the BIM platform to assess and analyze multi- and interdisciplinary efforts during the design process to evaluate building energy consumption [21].

V. Singh et al., also recommended that building information modeling (BIM) is a typical platform involving multi-disciplinary collaboration and plenty of building data, which can integrate the design aspects of architecture, structure, and electromechanics [22]. G. Costa and L. Madrazo emphasized the definition of components that represent the physical elements used in construction sites, described by the materials, dimensions, external features, cost, and other information. To enable an accurate and efficient selection of products and materials, a linked-data method was proposed by G. Costa to ensure the reusability, variability, connectivity, and normality of the components [23]. Li et al., created a BIM retrieval system, named BIMseek++, to search targeted BIM components in standard component libraries using semantic similarity measurement of attributes [24]. Similarly, Lee et al., recommended another platform aimed at finding appropriate BIM components based on probabilistic matrix factorization and an optimized grey model that shows the advantages and the significance of the components library [25].

Recently, digital delivery is a hot topic in civil integrated management. For instance, B. Sankaran et al., undertook an empirical study on highway projects that can prove the feasibility of digital data-centric project delivery, providing accurate data and information for transportation assets within the operation and maintenance (O&M) stage [26]. To conduct such a method, the Building and Construction Authority of Singapore launched integrated digital delivery (IDD) to accelerate delivery and to improve the performance of local smart construction [27].

2.2.2. Platforms in the Construction Phase

The construction phase links the design and O&M stage by realizing the design scheme and delivering the final building or infrastructure for O&M. In most cases, the construction phase tends to be the most complicated and laborious throughout the whole process. As a consequence, more research has been done in this area and more sophisticated management tools are desperately required to improve the quality of construction.

Considering individuals, especially personal training and safety, many studies have been done. Pan et al., explored the vocational training of construction workers in Guangdong Province of China by utilizing integrated methods of document analysis, field trip observations, meetings, and semi-structured interviews to reveal the importance of personal training [28]. J. Teizer et al., developed a new location tracking and data visualization technology with the help of global positioning system (GPS) and radio frequency identification (RFID) technology to improve ironworkers' education and training efficiency in safety and productivity [29]. Jin et al., put forward an IoT-based intrusion monitoring system, which can prevent construction safety accidents and improve intruder identifying and access-right assigning [30].

Another topic worth mentioning is the dispatch of building materials and machines. B.H.W. Hadikusumo et al., emphasized a conception of the procurement of construction materials using an Internet-based agency system, which can reduce some of the problems associated with the traditional material procurement process, such as facilitating supplier searches and access to product data information for construction companies [31]. Hadikusumo also decentralized a database platform equipped with electronic agents for material procurement. In addition, depending on the scale and the capital, different contractors prefer different approaches to handling machines. T. Prasertrungruang found that larger contractors often pay more attention to outsourcing strategies for equipment management and tend to dispose of or replace inefficient equipment frequently, while some companies can only buy used machines considering their finance and budget [32]. Hence, a platform focused on machines is needed. Hon-lun Yip et al., presented a comparative study on the applications of general regression neural network (GRNN) models to predict the maintenance cost of construction equipment that makes the cost of purchasing or renting machines controllable [33].

Currently, human–computer interaction, a frontier research topic, has been widely studied. For example, Fang et al., built a platform capable of capturing crane posture using sensors, automatically modeling it with point cloud data to analyze the operational risk of the crane [34]. S. Paneru compiled that computer vision assists humans in aspects of safety management, progress monitoring, productivity tracking, and quality control [35]. However, in this area, the lack of concentration on future scenarios exploration is a problem that cannot be ignored [34,36]. Therefore, Pan et al., developed a new tool for the construction robotics domain that can inform and support the practical requirements of management and systems engineering process through integrated scenario-based analysis [36].

As to resource management and information integration, early in 2010 BIM was frequently highlighted to integrate resources for production and construction [37]. In 2014, M. Safa et al., invented an integrated construction materials management model, which successfully addressed the challenges of dispatch materials, decreasing overall project cost [38]. The development of components management is also under revolution. Luo et al., focused on the advantages of prefabricated components, namely high productivity and quality through repeatability and mass customization, and outstanding environmental performance through reduced material use and construction waste [39]. Based on the BIM platform, Li et al., designed a components management platform supporting the Internet of Things (IoT) using positioning technologies such as RFID (radio frequency identification), UWB (ultra-wideband), and GPS (global positioning systems) to enable dispatch, transport, and assembly on-site [40].

Nowadays, smart construction sites win support from a range of countries and regions for their powerful information integration. Smart construction is a revolution of traditional construction ways, providing intelligent and efficient management for project schedule management, cost estimation, safety management, and quality management. To be specific, Jiang et al., established a safety management platform based on a cyber-physical system, warning and controlling mechanical and other risks through data awareness and data processing modules [41]. H. Alavi et al., presented a data model to automate the data transfer process for building condition assessment by concluding traditional BIM-based support for smart construction sites [42]. V. Ciotta et al., proposed a proof-of-concept introducing smart contracts that have different levels of complexity, and integrated blockchains and smart contracts to handle various common data environments (CDEs), which facilitated the formation of construction information flow platforms [43]. Nevertheless, the supervision of smart construction sites also needs supporting platforms. P. Kochovski and V. Stankovski put forward a new method of applying fog computing to achieve smart construction sites with the DECENTER fog computing and brokerage platform, which can address complex problems such as risk warning, real-time management, and construction process monitoring [44]. Li et al., proposed a FedSWP framework, the federated transfer learning enabled SWP for collecting and protecting the personal image information of construction workers in OHS management, to preserve information in smart sites [45]. Pan et al., presented a closed-loop digital twin framework under the integration of Building Information Modeling (BIM), Internet of Things (IoT), and data mining (DM) techniques for advanced project management to cope with data from various sources and documents in different formats [46].

Information is a critical factor in project management. Wu et al., established an ontological knowledge platform that stores the solutions to concrete bridge rehabilitation project management and offers an automated searching engine [47]. To make physical construction operations easier to understand and optimize, Pan and Zhang formed a digital twin framework integrating BIM, IoT, and data mining for advanced project management [46].

In addition, even the most intelligent construction sites are supposed to be inspected and checked meticulously. Since manual inspection has not only high subjectivity but also low accuracy, Tan et al., improved the method of automatic inspection data collection of building surfaces based on BIM and unmanned aerial vehicles (UAV), which set the foundations for the establishment of an automated testing platform [48]. Furthermore, G. Martinez et al., designed an unmanned aerial system (UAS) named iSafeUAS to timely recover onsite safety risks [49].

Another tricky issue in the construction industry is environmental problems. To be specific, each stage of the construction process consumes large amounts of energy and emits lots of pollutants into the atmosphere, especially CO_2 [50]. As a result, platforms related to waste management and green building are critical. Facing this situation, B. Ilhan and H. Yaman designed a deep convolutional neural network to deliver 94% accuracy in classifying images of various classes of construction and demolition waste (C&DW) [51]. Li and Zhang proposed a web-based construction waste estimation system (WCWES) for building construction projects, incorporating the concepts of work breakdown structure, material quantity takeoff, material classification, material conversion ratios, material wastage levels, and mass balance principle [52]. As for green buildings, Hong et al., developed a web crawler and two ontologies that enable automated management of green building material information (GBMI) and facilitated the process of green building certification tasks [53]. B. Ilhan and H. Yaman presented the green building assessment tool (GBAT), which implements the proposed model and aids the design team in the generation of documentation necessary for obtaining green building certification [51].

2.2.3. Platforms in Operation and Maintenance Phase

In this phase, digital twin (DT) is a topic both hot and frontier. Jiang et al., defined DT and concluded its applications in the civil engineering industry. Elements involving physical part, virtual model, the connection between physical and virtual models, and twin relationship between physical and virtual models are necessities of DT [54]. Hunhevicz et al., proposed a platform for executing performance-based digital payments by the connection of the digital building twin with blockchain-based smart contracts [55].

Smart decision-making methods always help humans to improve solutions; the same applies to the construction industry. Moretti et al., proposed a synthetic method called GeoBIM, a combination of location data from BIM and GIS, to support asset management decision making [56]. Based on BIM, Ma and Wu developed a fire emergency management system (FEM) consisting of fire intelligent monitoring, fire warning, fire response, and fire treatment to help decision making [57]. Additionally, Li et al., used an artificial neural network (ANN) and genetic algorithm (GA) to automate decision making in highway pavement preventive maintenance [58].

Similar to environmental issues mentioned in Section 2.2.2, the operation and maintenance phase is another energy consumer. Liu et al., established a real-time carbon emission monitoring system based on cyber-physical systems (CPS), emphasizing the greenhouse gases (GHG) emission problems in prefabricated construction [59]. Tanasiev et al., introduced a communication network based on the MQQT protocol to enhance environmental and energy monitoring of residential buildings [60]. EIZahed et al., implemented data mining techniques and utilized the power of big data to archive energy and petroleum projects [61].

2.2.4. Platforms through the Whole Process

A construction consultant is a typical link throughout the full construction process. To cater to clients, L. Chow and S. Thomas Ng mentioned that the complexity of the construction technology, long investment cycle, and huge investment amount of the project necessitated the component engineering consultants (ECs) to preserve the rights and interests of the clients [62]. M. Adesi et al., used hypothesis testing to prove that the pricing quantity surveying (QC) consultant services are significantly related to the delivery of construction projects within the planned budget, quality, and duration [63]. Both articles verified the necessity of consultant platforms.

Valid cost is one of the main targets during construction, which is fundamental to a project's ultimate success [64]. S. W. Moon et al., verified the effectiveness of utilizing historical cost data in an analytical OLAP (on-line analytical processing) environment to improve the accuracy of the developed cost data management system (CDMS) [65]. M. Niknam and S. Karshenas discussed a new approach to construction cost estimating that uses semantic web technology, providing infrastructure and a data modeling format that can access, combine, and share information over the Internet in a machine-processable format [66]. T. Akanbi and Zhang proposed a new semantic NLP-based method for developing construction specifications information extraction to support cost estimation [67].

While handling complex affairs on construction sites, the manual selection relies heavily on personal experience and judgment. Oftentimes, stakeholders have trouble matching the project characteristics well. To solve these problems, Wang and Kong proposed a GA-based model to assist with the project selection and auditor assignment process [68]. Wang and Yang analyzed the applications of an electronically facilitated bidding model preventing construction disputes and explained the advantages of avoiding issues around the accuracy of contracted quantities, the acceptability of unit prices of cos items, and whether the equivalent of a product can be used [69]. M. Gunduz et al., used Chi-square automatic interaction detector (CHAID) and classification and regression (CRT) decision tree algorithms to develop bid/no-bid models for design–bid–build projects for contractors [70]. All these innovations desperately require platforms to carry them. When dealing with complex construction problems, some construction units may do something illegal or immoral. Facing these phenomena, government supervision is the hallmark of the new era, which is essential to regulate construction behaviors and promote the continuous improvement of the quality of the comprehensive construction works [71]. To improve the efficiency of government supervision, Guo et al., attempted to realize its standardization and build a supervision system from the perspectives of the chief stakeholders and the operation [72].

Additionally, it is of great significance to establish systems or platforms to integrate data resources and supply chains. In this area, plenty of advanced Internet-based technology is utilized. For example, RezaHoseini et al., proposed a new comprehensive bi-objective mathematical model in the multi-project supply chain management for green construction [73]. J. Irizarry et al., combined BIM with GIS to strengthen the visual monitoring of construction supply chain management [74]. H. Hamledari and M. Fischer introduced the application of blockchain-based crypto assets to enhance the integration of cash and product flows [75]. To further their research, H. Hamledari and M. Fischer developed realized construction payment automation using blockchain-enabled smart contracts and robotic reality capture technologies, using a camera-equipped unmanned aerial vehicle (UAV) and an unmanned ground vehicle (UGV) to decentralize and accelerate the progress payment [76].

2.3. Identification of Platforms in the Construction Industry

By reviewing and summarizing the literature, 26 Internet-based platforms existing or eager to be established are sorted and the summary of these platforms is outlined in Table 1. As shown in Table 1, platforms ranging from F1 to F26 are classified by different stages in the construction process, mainly composed of reconnaissance survey of design phase and construction phase. Moreover, some of the platforms are taken advantage of during the whole process.

Table 1. Summary of construction industry Internet platform.

Num.	Platform	Phase	References
F1	Geography survey platform	Reconnaissance survey and design phase	[19,20]
F2	Collaborative design platform		[21,22]
F3	BIM components library		[23–25]
F4	Digital delivery platform	Construction phase	[26,27]
F5	Real name system for labor		[28–30]
F6	Materials purchasing platform		[31,32]
F7	Machines management platform		[32,33]
F8	Human–computer interaction platform		[34–36]
F9	Resource management platform		[37,38]
F10	Components management platform		[39,40]
F11	Smart sites management platform		[41–43]
F12	Smart sites supervision platform		[44–46]
F13	Information integration platform		[46,47]
F14	Inspection and Testing platform		[48,49]
F15	Building waste management platform		[50–52]
F16	Green construction platform		[51,53]
F17	Digital twin operation platform	Operation and Maintenance platform	[54,55]
F18	Smart decision-making platform		[56–58]
F19	Energy monitoring platform		[59–61]
F20	Consultant platform		[62,63]
F21	Cost estimation management platform		[65–67]
F22	Business approval platform	Whole process	[68,69]
F23	Bid management platform		[69,70]
F24	Supervision and Honesty platform		[71,72]
F25	Supply chain management platform		[73,74]
F26	Financial payment platform		[75,76]

3. Research Methodology

3.1. Framework of the Proposed Method

In general, the process of this research mainly contains two parts: determining the weights of factors influencing the Internet-based platforms and prioritizing different kinds of platforms in various construction stages. In the existing literature, scholars focus on innovation in technology, demand, policy, and applicable standards when discussing Industry Internet Platform (IIP) [77]. For example, Zhang et al., concluded influencing factors of IIP, including application capability, industrial service capability, and resource management capability [78]. Hao optimized the supply–demand with dual diversities for IIP [79]. As more and more attention is paid to the policy recently, Guo et al., insisted that it is the policy that makes the Internet globally sustainable [80]. Hence, the maturity of technology, the urgency of need, the feasibility of policy, and the perfection of standard are selected to assess the construction industry Internet platform. Firstly, AHP, which can effectively handle the problem of vagueness and subjectivity during the assessment, is adopted for weight criteria. In the second phase, 26 branches of Internet-based platforms identified by the literature review are prioritized. TOPSIS is applicable due to its proven advantages in terms of stability, concise principle, mathematical calculations, objective comparison, and its full use of statistics. The rank of platforms is analyzed using the TOPSIS method. The framework of the proposed method is depicted in Figure 2.

Considering the referred methods, AHP is limited to the amount of its criteria. With plenty of criteria to assess, the calculation of relevant parameters becomes extremely complex and consistency evidently declines. To achieve the goal of assessing and ranking the platforms, TOPSIS shows its strengths in handling more data. Moreover, weights of alternatives are seldom considered in the TOPSIS method, while AHP can indirectly offer the weights of criteria to calculate the weighted normalized matrix in TOPSIS steps [81]. To address these problems, AHP–TOPSIS was discovered by combining the AHP with TOPSIS and became a hybrid multi-criteria decision-making approach [82].

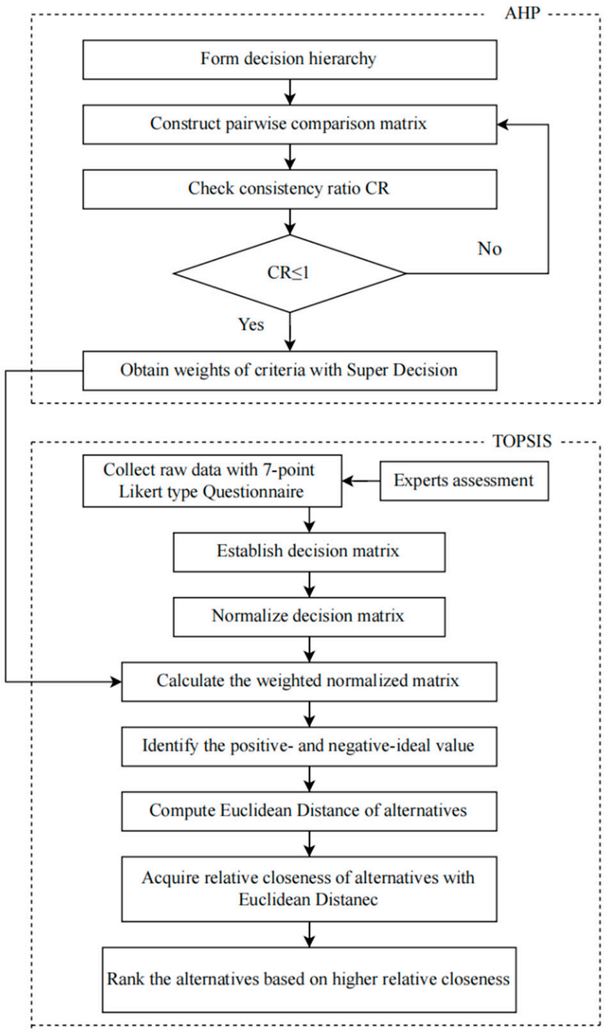

Figure 2. Framework of AHP–TOPSIS.

AHP was developed by Saaty in 1988 [83] and TOPSIS by Huang and Yoon in 1995 [84]. The integrated AHP–TOPSIS approach was utilized in this study to rank the branches of all aspects of the construction industry Internet platform [85]. In this way, the results will help practitioners receive comprehensive knowledge and urge stakeholders within the construction industry to facilitate the improvement of Internet-based platforms.

3.2. Weighting Factors Using AHP

AHP (Analytic Hierarchy Process) is an effective decision-making method for criteria weighting [86]. It provides the ability to measure the consistency of preferences, manipulate multiple decision makers and handle tangible and non-tangible criteria [87]. In the construction industry, AHP has been widely used and combined with other decision-making methods. With the goal of a new bridge rating, Contreras-Nieto et al., determined the weights of safety, serviceability, comfort, and resiliency regarding infrastructure assessment using AHP [88]. Similarly, P. Jaskowski et al., established weights of five criteria in the contractor prequalification to help contractor selection [89].

Due to its advantages of subjectivity and vagueness, this paper uses AHP to determine the weighting of the four indicators, the maturity of technology, the urgency of need, the feasibility of policy, and the perfection of standards.

Step 1: Construct the hierarchy. A typical AHP hierarchy consists of a precise goal at the top layer; criteria or options at the middle and the bottom are the alternatives. AHP with a single level is suitable for this study.

Step 2: Construct a group of pair-wise comparison matrices. The pair-wise comparison matrix of the *e*th expert is described as:

$$B = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1m} \\ x_{21} & 1 & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where x_{ij} $(1 \leq i \leq m,\ 1 \leq j \leq m)$ is the relative importance of criterion i on criterion j given by experts. According to the rule proposed by Buckley, x_{ij} is chosen from nine linguistic terms from 1 to 9. The regulation is described in Table 2.

Table 2. Rules of comparison matrix.

Value	Meaning of the Value When Comparing Two Factors
1	Two factors are equally important
3	One factor is slightly more important than the other
5	One factor is evidently more important than the other
7	One factor is strongly more important than the other
9	One factor is extremely more important than the other
2,4,6,8	Median of two adjacent judgments mentioned above

Step 3: Test the consistency. Calculate the maximum eigenvalue λ of B, then compute the consistency index $CI = \frac{\lambda - m}{m-1}$. The random consistency index (RI) can be found in Table 3, which is relative to the number of indicators m.

Table 3. Random consistency index.

m	3	4	5	6	7	8	9	10
RI	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Compute the consistency ratio $CR = \frac{CI}{RI}$. If $CR < 0.1$, the comparison matrix is regarded as valid and acceptable. Otherwise, the matrix should be abandoned and re-evaluated until $CR < 0.1$.

Step 4: Obtain the weights of the four evaluation indicators with the help of Super Decisions, where w_i represents the weight of the criterion in the ith.

3.3. Ranking Alternatives Using TOPSIS

Compared with AHP, TOPSIS does better in coping with large quantities of data. Recently, TOPSIS is frequently used in multiple objective decision making (MODM). Song-ShunLin et al., established a risk evaluation model for excavation relying on TOPSIS and set theory [81]. Abdelkader et al., proposed an improved algorithm-based TOPSIS method to prioritize the Pareto optimum maintenance plans [90].

TOPSIS was adopted in this study to evaluate and rank the branches of Internet-based platforms given by the literature review. The steps to execute the process of TOPSIS are shown below.

Step 1: establish the decision matrix according to the experts as follows:

$$V = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & P_{mn} \end{bmatrix} \quad (2)$$

where p_{ij} $(1 \leq i \leq m, 1 \leq j \leq n)$ is a crisp value, representing the score of the ith alternative assessed under the dimension of the jth factor. The alternatives in this study refer to the 26 types of Internet platforms and the factors are the four criteria mentioned before.

Step 2: Normalize the decision matrix $R\left(=\left[r_{ij}\right]_{m\times n}\right)$, where r_{ij} is computed as follows:

$$r_{ij}=\frac{p_{ij}}{\sqrt{\sum_{i=1}^{m}p_{ij}^{2}}} \tag{3}$$

This step makes comparison across attributes easier with dimensionless units [91].

Step 3: Calculate the weighted normalized matrix $\widetilde{V}\left(=\left[\widetilde{v}_{ij}\right]_{m\times n}\right)$. Considering the different weights owned by each criterion, $\widetilde{V}$ is calculated by multiplying the weights of criteria and the value p_{ij} shown in decision matrix V.

$$\widetilde{v}_{ij}=w_i\times r_{ij} \tag{4}$$

Step 4: Determine the positive-ideal value (A_j^*) and negative-ideal value (A_j^-).

$$A^*=\{v_1^*,\ v_2^*,\cdots,v_i^*\}=\left\{\left\langle\max\left(v_{ij}\right)\middle|\ j\in J^*\right\rangle,\left\langle\min\left(v_{ij}\right)\middle|\ j\in J^-\right\rangle\ \middle|\ i=1,2,\cdots,m\right\} \tag{5}$$

$$A^-=\{v_1^-,\ v_2^-,\cdots,v_i^-\}=\left\{\left\langle\min\left(v_{ij}\right)\middle|\ j\in J^*\right\rangle,\left\langle\max\left(v_{ij}\right)\middle|\ j\in J^-\right\rangle\ \middle|\ i=1,2,\cdots,m\right\} \tag{6}$$

where J^* is the assembly of benefit criteria and J^- represents cost criteria.

Step 5: Calculate the Euclidean distance. Euclidean distance is also called separation value, measuring the distance from each alternative to the positive- and negative-ideal value, which is expressed by N-dimensional Euclidean distance.

The formulas of positive-ideal solution $\left(S_i^*\right)$ and negative-ideal solution $\left(S_i^-\right)$ are shown as:

$$S_i^*=\sqrt{\sum_{j=1}^{m}\left(v_{ij}-v_j^*\right)^2} \tag{7}$$

$$S_i^-=\sqrt{\sum_{j=1}^{m}\left(v_{ij}-v_j^-\right)^2} \tag{8}$$

Step 6: Compute the relative closeness to the ideal value $\left(C_i^*\right)$. The value of C_i^* means the overall preference score earned by the ith alternative.

$$C_i^*=\frac{S_i^-}{S_i^*+S_i^-},\ i=1,2,\cdots,m. \tag{9}$$

C_i^* takes values between 0 to 1. The higher the value C_i^* is the closer the ith indicator is to the target value, and vice versa. Alternatives, the clarified 26 Internet-based platforms, are ranked based on higher C_i^* values.

4. Data Collection and Results

4.1. Determining Weights of Criteria

To make the judgements accurate and objective, experts from different fields, including construction units, supervision units, design units, universities, and governments, are invited to fill in the questionnaire. The questionnaire is designed for the AHP–TOPSIS method mentioned in Section 3. To execute the process of this study, the first step is to weight the chosen criteria using AHP. The assessment considers maturity of technology, the urgency of need, the feasibility of policy, and the perfection of standards; abbreviated as MT, UD, FP, and PS. The invited experts are required to compare and judge the importance of each of them in their position. The synthetic comparison matrix is computed in Table 4. As is described in Section 3.2, Super Decision helped process the data and eventually obtained the weights ($w_1=0.3355$, $w_2=0.4646$, $w_3=0.1276$, $w_4=0.0723$).

Table 4. Results of the comparison matrix.

Criteria	MT	UD	FP	PS	Weight
MT	1	0.647	2.982	4.632	0.3353
UD	1.546	1	3.942	5.323	0.4635
FP	0.335	0.254	1	2.156	0.1294
PS	0.216	0.188	0.464	1	0.0728

4.2. Outcome of Data Processing

First of all, the experts were asked to evaluate the identified Internet platforms and then assign scores to each of them according to a 7-point Likert-type questionnaire. The Likert-type questionnaire is an effective data collection method, with 1 to 7 representing the gradually rising degree of agreement to various presentations [92]. The outcome of data collection is shown in Table 5.

Table 5. Results of the decision matrix.

Platforms	MT	UD	FP	PS
F1	4.10	3.20	1.80	2.00
F2	4.20	4.70	5.00	3.10
F3	5.80	6.40	6.00	4.80
F4	2.80	3.50	4.00	1.50
F5	5.80	6.20	6.20	4.50
F6	5.10	5.00	2.80	2.10
F7	3.70	3.90	3.50	2.80
F8	2.50	2.90	3.10	3.50
F9	2.90	3.40	1.50	1.50
F10	3.80	3.80	2.20	3.20
F11	3.70	4.90	6.10	5.10
F12	3.10	3.90	4.20	4.10
F13	2.70	4.10	3.10	1.40
F14	3.00	5.00	4.60	2.60
F15	2.60	2.60	4.20	2.00
F16	1.80	2.30	5.00	3.40
F17	4.30	2.90	5.30	3.20
F18	2.10	2.30	1.80	2.00
F19	1.80	2.00	4.50	2.30
F20	6.00	4.30	4.70	5.00
F21	4.40	4.60	3.00	2.30
F22	5.00	6.10	4.80	2.00
F23	4.90	6.90	4.20	3.20
F24	6.40	5.90	4.90	4.90
F25	1.30	2.20	2.10	1.50
F26	2.50	2.50	2.60	4.20

After acquiring the raw data, the next step was to obtain the final TOPSIS ideal value following Section 3.3. Table 5 aggregates the calculation results of normalization and weighting. Moreover, the positive-ideal solution (S_j^*) and negative-ideal solution (S_j^-) of each column are listed in the last two lines. Table 6 shows the outcomes after the normalization and weighting of the decision matrix.

4.3. Ranking the Alternatives

The calculation process was performed by MATLAB. The worked out ideal value (C_i^*) and ranked order of the platforms by the value height are shown in Table 7.

Table 6. Results of the weighted normalized decision matrix.

Platforms	MT	UD	FP	PS
F1	0.0681	0.0677	0.0110	0.0088
F2	0.0698	0.0995	0.0305	0.0137
F3	0.0964	0.1354	0.0366	0.0212
F4	0.0465	0.0741	0.0244	0.0066
F5	0.0964	0.1312	0.0379	0.0199
F6	0.0847	0.1058	0.0171	0.0093
F7	0.0615	0.0825	0.0214	0.0124
F8	0.0415	0.0614	0.0189	0.0155
F9	0.0482	0.0719	0.0092	0.0066
F10	0.0631	0.0804	0.0134	0.0141
F11	0.0615	0.1037	0.0372	0.0225
F12	0.0515	0.0825	0.0256	0.0181
F13	0.0449	0.0868	0.0189	0.0062
F14	0.0498	0.1058	0.0281	0.0115
F15	0.0432	0.0550	0.0256	0.0088
F16	0.0299	0.0487	0.0305	0.0150
F17	0.0714	0.0614	0.0324	0.0141
F18	0.0349	0.0487	0.0110	0.0088
F19	0.0299	0.0423	0.0275	0.0102
F20	0.0997	0.0910	0.0287	0.0221
F21	0.0731	0.0973	0.0183	0.0102
F22	0.0831	0.1291	0.0293	0.0088
F23	0.0814	0.1460	0.0256	0.0141
F24	0.1063	0.1249	0.0299	0.0217
F25	0.0216	0.0466	0.0128	0.0066
F26	0.0415	0.0529	0.0159	0.0186
A^*	0.1063	0.1460	0.0379	0.0225
A^-	0.0216	0.0423	0.0092	0.0062

Table 7. The rank of the alternatives.

Rank	Num.	Platform	C_i^*
1	F3	BIM components library	0.8939
2	F5	Real name system for labor	0.8696
3	F24	Supervision and Honesty platform	0.8426
4	F23	Bid management platform	0.8068
5	F22	Business approval platform	0.7664
6	F6	Materials purchasing platform	0.6342
7	F20	Consultant platform	0.6294
8	F11	Smart sites management platform	0.5649
9	F2	Collaborative design platform	0.5643
10	F21	Cost estimation management platform	0.5456
11	F14	Inspect and Testing platform	0.5046
12	F7	Machines management platform	0.4210
13	F10	Components management platform	0.4084
14	F17	Digital twin operation platform	0.3893
15	F12	Smart sites supervision platform	0.3892
16	F1	Geography survey platform	0.3654
17	F13	Information integration platform	0.3648
18	F4	Digital delivery platform	0.3104
19	F9	Resource management platform	0.2853
20	F8	Human–computer interaction platform	0.2205
21	F15	Building waste management platform	0.2115
22	F26	Financial payment platform	0.1871
23	F16	Green construction platform	0.1697
24	F19	Energy monitoring platform	0.1364
25	F18	Smart decision-making platform	0.1081
26	F25	Supply chain management platform	0.0402

5. Discussion

According to the computed outcomes in Section 3, the identified platforms are divided into three groups, each group representing a development stage in this era. As is shown in Figure 3, according to the Ideal Value C_i^*, 0.6 is a dividing line between Platform 1.0 and Platform 2.0 and 0.3 is the threshold value of Platform 3.0.

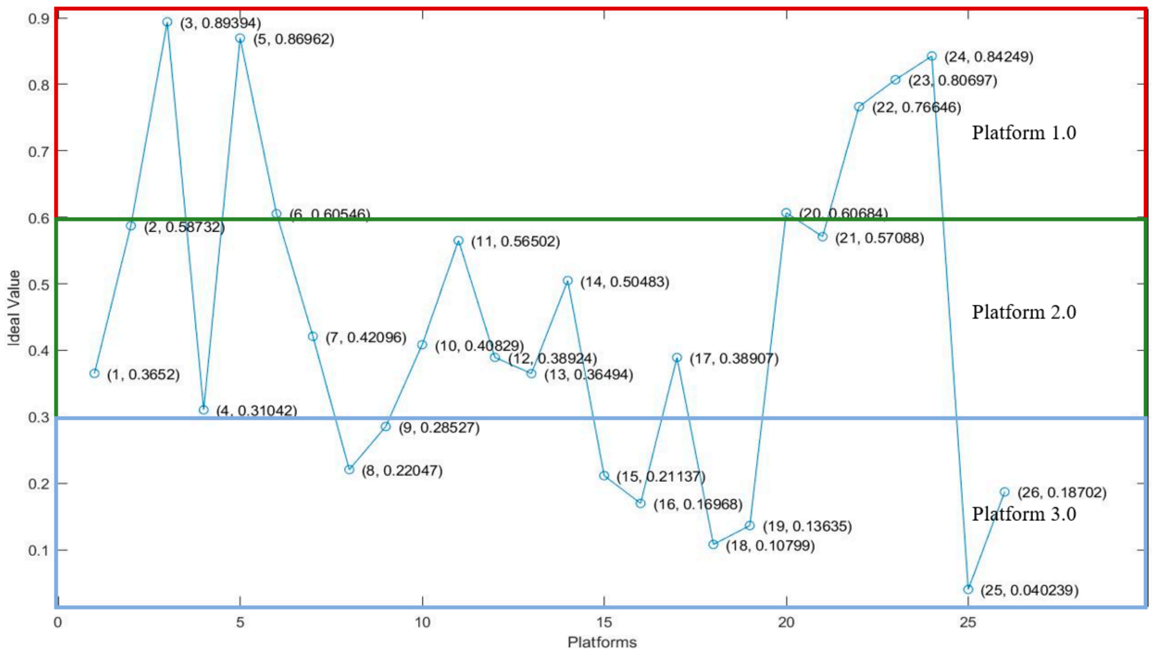

Figure 3. Development stage division of the construction industry Internet platform.

Platform 1.0 is the first stage of the construction industry Internet platform, namely the Foundation Construction Stage. This stage contains the development direction of seven partial platforms headed by the BIM components library. Regarding establishing vertical segmentation platforms as its core, related departments should focus on a specific value or functions of the Internet-based platforms. As is shown in Figure 3, platforms in this stage tend to be informatively oriented, realizing the basic layout of functions and committed to solving simple problems within respective fields. This is highly in accordance with the conclusion drawn by F. Elghaish; the IoT and blockchain in Industry 4.0 are mainly used in independent discrete processes of construction projects such as components management, bid management, and energy monitoring [93]. The platform construction in this stage is mainly based on construction units and effectively solves the management problem concerning man, materials, and machines, improving intelligent management methods. The government should also actively take part in information management to create a transparent, efficient, and concise environment for platform development. In the platform 1.0 stage, the construction industry is initially upgraded to industrial, digitized, and intelligent transformation.

Platform 2.0 is named the Functional Developing Stage. In the case of the basic functional construction, the functions of Internet-based platforms are expanded. Due to platform-based management in this stage, the construction process shows two features. One is using Big Data to improve the platform itself [11]. Sun and Zhang explored the application value of big data for low carbon emission and green environment, which conversely facilitate the decentralized distribution of blockchain big data platform [13,94]. Through data analysis and mining, platforms assist decision guidance production. Taking the cost estimation management platform as another example, relying on simple functions realized in the last stage such as the BIM component library, this platform can establish a large database of project cost information, integrated resources, and data, then build large data analysis centers [23]. Moreover, engineers can use a comprehensive engineering cost information resource database to achieve centralized management of cost information through data analysis, assist decisions, and ultimately achieve results of cost reduction [66,67]. Another outlining feature is the extension of the platform function, including, but not limited to, expanding downstream of the industrial chain in functional initial fusion [95]. For instance, the information integration platform integrates the information of the upstream material equipment supplier through the upstream supply of the industry chain and the construction of the middle reaches, which enhances the capacity of comprehensive management [47]. All kinds of units in platform 2.0 are supposed to deepen the construction of existing platforms and achieve platform building with higher levels of functionality by solving core technical problems.

Platform 3.0 is the Platform Fusion Stage. After the construction of platform 1.0 basic functions, platform 2.0 is further developed and improved. As the final stage of the development path of the construction industry Internet platform, instead of a functional further improvement the integration of platform functions is the stage of compounding development, accompanied with a decrease in the number of platforms. Similar to existing studies on development paths of other fields in the construction industry, achieving ultimate goals requires the collaboration of many stakeholders [96]. This stage requires continuous efforts from not only construction units and design units but also governments to constantly lay out platform integration and emerging technologies. Specifically, the integration of platform functions will enhance the maturity of the platform and the expansion of the platform service [1]. The integrated internet-based platforms contribute to a platform-grade connection between the whole industry chain and the supply chain and achieve synergistic cooperation during the whole construction process, which enables all participants to facilitate the use of platforms and to enjoy the convenience [74]. The platforms of the full industrial chain promote the innovation of the construction industry, making stakeholders attach attention to the conception of smart construction and lean construction. During Platform 3.0, it is the positioning of the service providers that greatly affects the development path of the Internet-based platforms in the construction industry. With the improving capacity of related enterprises, the overall advantages of the construction industry Internet platform will be significantly enhanced.

6. Conclusions

Since there is a lack of research on the construction industry Internet platform, the development path of the platforms is ambiguous, which is a barrier to enhancing the comprehensive construction performance in this era. With the rapid development of intelligent technologies, more and more modern construction tools are adopted in smart construction sites. However, these new technologies desperately need platforms to carry and integrate them. As a result, this paper focuses on the development path of Internet-based platforms to help related departments understand the situation and to provide a basis for formulating development policies for the Internet-based platforms in the construction industry.

In this paper, the features and branches of the construction industry Internet platform are first identified through a literature review. Then, an AHP–TOPSIS method is adopted to rank the identified platforms. The construction industry Internet platform is an effective management medium, which contains six main features: data informatization, big data analysis, resource integration, knowledge informatization, digital delivery, and network cooperation. The construction industry Internet platform is a new combination of information communication technology and modern construction technology and is an important carrier to facilitate digital and smart construction. The development path of these platforms can be divided into three stages: Platform 1.0 (Foundation Construction Stage), Platform 2.0 (Function Developing Stage), and Platform 3.0 (Integration Stage). Depending on the explored path in this paper, stakeholders within the construction industry can own a clear view of the development rules of the Internet-based platforms. Furthermore, the intention of smart construction and lean construction can be greatly facilitated by the platforms.

The development of the construction industry Internet platform is still in its infancy, therefore the evaluation criteria and branches of Internet-based platforms in the construction industry have not been explored before. Therefore, this article contains the limitation that the listed criteria and branches of these platforms may not be comprehensive. Moreover, with all experts from Asia, mainly in China, the judgments tend to be based on the general environment in China. To continue further research, more experts from more countries or areas should be interviewed to form a better-established assessment, then the sustainable development path for a global construction industry Internet platform should be derived.

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