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ORIGINAL ARTICLE

TRANSFORMATION OF INDUSTRIAL REVOLUTION 4.0 IN THE CONSTRUCTION INDUSTRY: UNDERSTANDING DRIVERS & BARRIERS WITH DEMATEL ALGORITHM

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ABSTRACT – Modern digitalization technology known as Industrial Revolution 4.0 (IR 4.0) has the potential to enhance business operations and communication networks across a variety of sectors. The lack of high-tech processes and technology in the construction industry, however, is growing the distance between the industry and IR 4.0 change. There has not been any prior research on the drivers and challenges of the IR 4.0 transition in the construction industry using DEMATEL. Therefore, the DEMATEL method was utilised to assess the interaction between the drivers and barriers of the IR 4.0 revolution in the construction industry. From the literature review, a list of factors that influence and hinder growth was taken. During interviews, 17 experts provided data using the DEMATEL questionnaire, which was subsequently used for analysis. The impact-relation map diagram showed key elements and their relationships. The outcome demonstrates challenges with the Incompatibility of Innovations (P) is the most significant issue, which is a major barrier that must be overcome. As a result, the listed drivers can be improved further, and the mentioned barriers can be overcome

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INTRODUCTION

Construction is a vital business in the majority of nations since it is an economic activity that greatly advances a nation (Pheng &Hou 2019). By incorporating digital technology and construction automation, the worldwide construction industry has recently tried to transform the effectiveness and productivity of construction. Due to the construction industry's inability to keep up with technology advancements that potentially increase productivity, labour productivity has stagnated (Livotov et al. 2019). Therefore, it is crucial to integrate tools and technology to raise productivity and increase quality. The construction industry has suggested intelligent machines, digital technologies, and sensor systems during the Industrial Revolution 4.0 (IR 4.0), often known as the Fourth Industrial Revolution (Craveiro et al. 2019). IR 4.0 is a cutting-edge digitalization technology that could improve operations, production, and communication networks across a variety of industries (Zabidin et al. 2019).

Although technology is readily available, IR 4.0 has yet to be fully implemented in Malaysia's building sector (Alaloul et al. 2020). The production problems are made worse by Malaysia's lack of personnel with the necessary knowledge of IR 4.0. Additionally, there are not enough publications to adequately cover the subject of IR 4.0 in the construction industry. The relationship between the drivers and barriers of the IR 4.0 transition in the construction industry utilizing the DEMATEL technique has not been studied. Therefore, the objectives of this study are twofold; to evaluate the critical drivers of IR 4.0 transformation in the construction industry by using DEMATEL, and to evaluate the critical barriers of IR 4.0 transformation in the construction industry by using DEMATEL. It is hoped that this study will help students and future researchers to improve the understanding of the interrelationship between drivers and barriers of IR 4.0 transformation in the construction industry for further research development.

LITERATURE REVIEW

IR 4.0 was first launched in 2011 by the German Industry-Science Research Alliance. The connectivity of information and communication technology is the fundamental component of the Fourth Industrial Revolution (Georg et al. 2015). In IR 4.0, a fresh method of industrial production is emerging thanks to communicative items, autonomous machines, and intelligentmachines. In addition, IR 4.0 relies on three main components: digitalized goods and services,integrated and digitalized networks, and new business models.

Industrial Revolution 4.0 in Construction Industry

The term "Industry 4.0" refers to the high-tech approach of the Fourth Industrial Revolution, which came about after the rise of electricity, mechanisation, and computerization (Dallasega et al. 2018). Although the industrial revolution was initially and primarily applied to the manufacturing industry, IR 4.0 is gradually reshaping the construction industry in

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the age of digital transformation (Low et al. 2019). In order to improve productivity and performance, the construction industry must overcome a wider range of obstacles than the manufacturing sector (Boadu et al. 2020). As a result, the level of uncertainty and mutability is raised by the building industry's complexity. Building Information Modelling (BIM) has recently become the primary tool for digitisation in the building industrial environment (Li & Yang 2017). Modularization, robotics, product lifecycle management (PLM), and information and communication technology are some of the ideas and technologies (Dallasega et al. 2018). Virtual reality, augmented reality, and human-computer interaction are other key elements of IR 4.0 that help the construction industry go digital.

Impacts and Benefits of Industrial Revolution 4.0 on Construction Industry

Every advancement in technology and innovation is important for businesses or organisations. However, because IR 4.0 will fundamentally alter the production and building manufacturing processes, the focus on interconnection and digital transformation improvements will provide new obstacles for construction organisations (Pereira & Romero 2017). According to Horváth and Szabó (2019), IR 4.0 is anticipated to have a significant impact on the construction market and industry, affect the entire product lifecycle, improve operational procedures, and boost a company's competitiveness. Six broad categories can be used to categorise the advantages of IR 4.0 for the construction industry: (1) industry, (2) economy, (3) market and business models, (4) work environment, (5) products and services, and (6) competency development. The new construction manufacturing vision can be recognised by digitised and decentralised production where the production components can independently govern and manage themselves, set off responses, and react to changes in their surroundings (Erol et al. 2016). The country's economy may be impacted by the introduction of IR 4.0 and the growing innovation and technology breakthroughs. The ways of selling goods and providing services have altered and influenced traditional businesses as a result of the rise of innovative technologies in IR 4.0, creating new opportunities and business models (Glova et al. 2014).

DRIVERS OF INDUSTRIAL REVOLUTION 4.0

Competitiveness

Humanity, society, and nations are on the verge of a new age, one that will be characterised by IR 4.0, which will provide global drivers and opportunities for the new era (Bal & Erkan 2019). Therefore, every country's leader and business decision-makers attempt to establish long-term strategies and innovative actions as well as seek solutions, notably focusing on development, in light of the drives created by IR 4.0 and the negative effects of globalisation. In IR 4.0, technology, innovation, labour capital, agility, and flexibility are the most important components for achieving economic success (Arnold et al. 2018). To boost their nation's economy, leaders must make use of digital technology and integrate them with other potential competitiveness elements

Continuous need for Quality and Productivity

With the advent of IR 4.0, new paradigms for managing techniques will emerge (Fettermann et al. 2018). As a result of the Fourth Industrial Revolution, every industry has been set up for new production processes (Horváth & Szabó 2019). By exploiting the internet and extensive communication networks, cyber-physical systems (CPS) enable application in new productive processes (Brettel et al. 2014). Through IR 4.0, which has several benefits like improved quality and efficiency, cheaper prices or budgets, and increased sustainability, the worldwide construction industry is also integrating new digital technology.

Customers' Expectations and Needs

The digitization of Industry 4.0 is a response to the quick changes in customer expectations and needs (Nagy et al. 2018). Additionally, not only the product itself needs to be updated over time, but also the production and operation technologies in order for them to adapt to the demands and requirements of the customer's products (Herrmann et al. 2014). In addition, customer data integration can be used to convert IR 4.0 in the construction business in order to meet customers' expectations and wants. Some businesses will examine past data regarding past customers' ordering needs and patterns in order to identify any potential trends and demands. As a result, it is simpler to adjust the demand predictions to reflect a more precise picture of customers' demands.

Technological Advancement and Digitization of Production

IR 4.0 is built on a variety of cutting-edge technologies (Rüßmann 2016). The conversion of production from traditional production to automated and optimised manufacturing through the use of new technology results in increased productivity and efficiency. The Internet of Things (IoT), big data, augmented reality, simulation, cloud computing, additive manufacturing, CPS, and advanced robotic system or autonomous vehicle are the eight key technologies for IR 4.0. These technologies are still at the forefront of the construction industry's transition to Industry 4.0.

DRIVERS OF INDUSTRIAL REVOLUTION 4.0

Lack of Employees Acceptance

As IR 4.0 will significantly change manufacturing processes in order to increase productivity and efficiency, it is envisaged that human workers would keep up with technological advancements by creating inventions and collaborating in a cooperative setting. This notion, however, requires employees' acceptance to deploy autonomous workers to help their production processes function smoothly (Prassida & Asfari 2022). The adoption of new technology has become a crucial step for digital transformation, which has become a crucial challenge for businesses in the age of the fourth industrial revolution (Chung et al. 2022). Many companies overlook the employees' acceptance and concerns about data transparency, dependence on technical assistance systems and human-machine interaction systems (Müller et al. 2018). Employees' acceptance and concerns play an important negative role when companies decide to implement or adopt new digital technologies (Newman et al. 2020). Therefore, in order to implement IR 4.0 technologies, companies must try to overcome this barrier or obstacle so that they can prevent failure in the implementation of IR 4.0 technologies. In order to support and implement IR 4.0, businesses must first develop a set of technological competencies while taking into account their location in relation to the technological frontier and the broader environment for the development, adoption, and application of IR 4.0 technologies (Peerally et al. 2022). Stakeholders, legislators, academics, and project managers must therefore concentrate on making IR 4.0 technologies simple to use and accept (David et al. 2022).

Lack of Financial Resources

Excessive investment costs, which may exceed the anticipated corporate development, will eventually result in an economic deficit when IR 4.0 is implemented in a company. Because of how it is developed and implemented, IR 4.0 is difficult for businesses and industries because it is like a process that uses building blocks (Ling et al. 2020). One of the biggest obstacles for businesses is the lack of finance or financial resources to support the adoption of IR 4.0. Another roadblock to IR 4.0 is the under-representation of economic benefits in the public consciousness. Therefore, the management team of the organisation is reluctant to adopt IR 4.0 technology due to the unpredictability of the costs and benefits.

Lack of Expertise

To enjoy the advantages brought about by the Industrial Revolution 4.0, resources and capabilities must be put in place. To ensure the success of the Industrial Revolution, resources and expertise in the exploitation of big data are required (Ashaari et al. 2021). With the incorporation of technology and digitization into manufacturing processes in recent years, the idea of a fourth industrial revolution (4th IR) has gained popularity (Castelo-Branco et al. 2022). The fourth industrial revolution's technological advancements put the industrialization model in danger and put its workers at risk of being replaced (Enzmann & Moesli 2022).

Technological skills are greatly desired and management teams are concerned with the issue of expertise in order to implement IR 4.0 (Ling et al. 2020). A shortage of skilled workers for jobs in a digital and smart workplace will affect nearly all human resource departments (Tupa et al. 2017). In addition, businesses need highly qualified and skilled workers who can operate and manage advanced production systems and facilities as well as evaluate and examine data gathered from digital machines, customers, and international resources required by IR 4.0 (Gehrke et al. 2015).

Lack of Data Privacy and Security

Because the IR 4.0 platform is web-based or cloud-based, data privacy and security are the two main issues for the majority of manufacturers. Companies with corporate value chains that may share and receive data via Cyber Physical System (CPS) or the Internet of Things (IoT) are one of the ideal scenarios for IR 4.0. However, due to a lack of funding and expertise, many businesses are unable to fully implement CPS or IoT. In addition, different commercial firms could have different cybersecurity hierarchies or levels. Consequently, it will result in the revealing of private information and data. To improve data and information protection, IR 4.0 would need to raise the bar for security architecture and security by design.

Lack of Awareness of Industrial Revolution 4.0

The construction industry currently lacks clear IR 4.0-related road maps, instructions, and guidelines that can facilitate their introduction and execution (Schumacher et al. 2016). Despite the introduction of numerous key digital technologies and the discussion of their importance, the exactness and preciseness of IR 4.0 are still mostly undefined and ambiguous. In addition, the actual principles and criteria of IR 4.0 are unclear because no definition or significance is used to represent IR 4.0 in tangible terms (Nyberg et al. 2016). It is challenging to measure return on investment without a precise and detailed benchmark as well as to establish precise and long-term IR 4.0 maps, plans, and strategies due to the lack of awareness and comprehension of IR 4.0.

Lack of Awareness of Industrial Revolution 4.0

In the early stages of IR 4.0, the majority of enterprises are worried about the suitability of technologies and facilities (Prause 2019). Additionally, they are worried about the efficiency, efficacy, and cost-benefit of facilities and technologies. Managing and analysing massive amounts of data and turning that data into useful information constitutes yet another challenge in IR 4.0. Transforming the valuable data obtained from numerous intelligent devices into a standard format is a problem that is currently unresolved throughout the implementation of IR 4.0. The three most common information risks in process management are information loss, information integrity loss, and information availability (Qian et al. 2017.

Incompatibility of Innovations

Many organizations that are having problems with technology will find it difficult to innovate and introduce new goods and services (Ling et al. 2020). Different lifecycle levels of smart machines adopted by businesses, along with varying degrees of autonomous systems and operations, will cause some machine parts to need replacement at various intervals, while the rest will require varying degrees of technological retrofitting (Müller et al. 2018). Every scale of business must ensure that the new systems are suitable and compatible with existing IT structures and operation systems unless the new technologies can completely replace the existing systems with controllable risk.

METHODOLOGY

DEMATEL is particularly useful for analyzing cause-and-effect interactions between the system's components since it uses directed graphs (digraph). By constructing the digraph, DEMATEL is able to demonstrate how the components are interdependent with one another (Kaushik and Somvir 2015). The DEMATEL method consists of the following six steps:

Step 1: Collect opinions from experts and calculate average matrix Z

Data was gathered from 17 people, including directors, general managers, senior managers, managers, project managers, engineers, executives, and town planners. These people were all deemed construction industry experts because they all had at least 6 years of relevant work experience. Experts were asked to assess the magnitude of the drivers' and obstacles' interdependence using an integer score (0-4).

Every expert was requested to rate the level of direct impact between 2 criteria (driver vs driver, barrier vs barrier) using integer scores. The degree to which the expert perceives the criterion *i* to impact the criterion *j* is recorded as x_{ij}. The integer score range is classified into 0 (No impact), 1 (Low impact), 2 (Moderate impact), 3 (High impact) and 4 (Very high impact) individually. When *i* = *j*, the integer score was set to zero (0). An *n* x *n* non-negative matrix was derived as $X^k = [x_{ij}^k]$, where *k* is the number of experts involved with $1 \le k \le m$. A group of *m* experts are used in this step. Thus, X^1, X^2, X^3, ..., X^m are the matrices from *m* experts. To summarize all judgements from *m* experts, the average matrix Z = $[z_{ij}]$ is derived as below:

$$z_{ij} = \frac{1}{m}\sum_{i=1}^{m} x_{ij}^k \tag{1}$$

Step 2: Calculate the normalized initial direct-relation matrix D

The normalized initial direct-relation matrix *D*, where all the values in the resulting matrix *D* is ranged between [0,1]. The formula used is as follows:

$$D = \frac{Z}{\lambda} \tag{2}$$

where

$$\lambda = \max\left[\max_{1\le i\le n} \sum_{j=1}^{n} Z_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} Z_{ij}\right] \tag{3}$$

All the elements in this normalized initial direct-relation matrix D will fall only in therange between zero (0) and one (1).

Step 3: Develop the total relation matrix T

The equation T = D $(I - D)-1$ was used to get the total-influence matrix T where I is n × n identity matrices. The element $Tiiii$ indicates the indirect influence of criterion i on criterion j, and then matrix T indicates the overall connection among each pair of criteria.

$$T = D\,(I - D)-1 \tag{4}$$

Step 4: Determine the sums of columns & rows of matrix T

In the total-influence matrix T, the row and column sums are calculated using the following formulas, which are indicated by vectors r and c, individually.

$$r = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}, \quad (5)$$

$$c = [c_j]'_{1\times n} = \left(\sum_{j=1}^{n} t_{ij}\right)'_{1\times n}, \quad (6)$$

Where $[c_j]'$ is expressed as transposition matrix.

Let r_i be the sum of i^{th} row in matrix *T*. The value of r_i represents the sum given both directly and indirectly effects, that criterion *i* has influence on the other criteria.

Let c_j be the sum of the j^{th} column in matrix *T*. The value of c_j represents the sum of all other criteria received both directly and indirectly, that all other criteria have on criterion *j*. If *j*=*i*, the value of (r_i+ c_j) indicates the overall effects both given and received by criterion *i*. The difference is that the value of (r_i− c_j) shows the net contribution of the criterion *i* to the system.

Step 5: Determine threshold value

A threshold value was set to develop the directed graph. According to Chia-Li Lin (2009), Matrix T displays impacts that are greater than the threshold value. The calculation's formula is displayed below:

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N} \quad (7)$$

Where N is the total number of criteria in matrix *T*.

Step 6: Create a causal relationship-directed graph

The directed graph (digraph) will be constructed by mapping all coordinate sets of (r_i + c_j, r_i − c_j) to illustrate the complex interrelationship where (r_i + c_j) represents the horizontal axis (*x*-axis) while (r_i − c_j) represents the vertical axis (*y*-axis). The criteria that t_{ij} is higher than α are selected and shown in the digraph. This will clearly define the interrelationship between the criteria.

RESULTS

Applying DEMATEL method on the Drivers of IR 4.0 transformation in the construction industry

Experts' responses were analysed accordingly. Table 1 below shows the list of drivers of IR 4.0 transformation in the construction industry.

Table 1. List of Drivers of Industrial Revolution 4.0 Transformation in Construction Industry

Criteria	Drivers of Industrial Revolution 4.0 Transformation
A	Competitiveness
B	Continuous need for quality and productivity
C	Customers' expectations and needs
D	Technological Advancement and Digitization of Production

Equation 1 was used to calculate the average matrix Z (drivers vs drivers) based on the ratings provided by the 17 experts, which is displayed in Table 2 below.

Table 2. Average Matrix Z (Drivers vs Drivers)

DRIVERS	A	B	C	D	SUM
A	0	3.176471	2.352941	3.529412	9.058824
B	3.117647	0	3.235294	2.117647	8.470588
C	2.764706	3.294118	0	2.411765	8.470588
D	3.411765	3.235294	2.705882	0	9.352941
SUM	9.294118	**9.705882**	8.294118	8.058824	

As shown in Table 2, the value 9.705882 is chosen to normalize Matrix Z, which leads to the formulation of Matrix D, with Equation (2) and Equation (3). The normalized initial direct-relation matrix D (Drivers vs Drivers) is shown in Table 3 below:

Table 3. Normalized Direct-Relation Matrix D (Drivers vs Drivers)

DRIVERS	A	B	C	D
A	0	0.327273	0.242424	0.363636
B	0.321212	0	0.333333	0.218182
C	0.284848	0.339394	0	0.248485
D	0.351515	0.333333	0.278788	0

By applying Equation (4), the total relation matrix T (Strategies vs Strategies) is portrayed in Table 4 below:

Table 4. Total Relation Matrix T (Drivers vs Drivers)

Drivers	A	B	C	D
A	2.495875	**2.823229**	2.486975	2.505180
B	**2.594736**	2.431551	2.411725	2.291519
C	**2.575089**	**2.685720**	2.163041	2.308339
D	**2.811669**	**2.885004**	**2.559935**	2.287986

By using Equations (5) and (6), the sums of rows and columns of Matrix T (Strategies vs Strategies) are calculated and illustrated in Table 5.

Table 5. Sum of Rows and Columns of Matrix T (Drivers vs Drivers)

Drivers	SUM R	SUM C	R+C	R-C
A	10.311260	10.477369	20.788629	-0.166109
B	9.729531	10.825504	20.555035	-1.095973
C	9.732190	9.621676	19.353866	0.110513
D	10.544594	9.393024	19.937618	1.151569

With reference to Total Relation Matrix T (Table 4), the threshold value α was calculated using Equation (7), and the threshold value was recorded as α =2.519848. Based on Table 5, a directed graph (digraph) was created to highlight the impact or influence of each component on others. This graph made it very evident how each factor related to the others, as seen in Figure 1 below. The data set of (ri + cj, ri - cj) will be mapped to produce the causal relationship diagram, where (ri + cj) represents the horizontal axis (x-axis) and the level of influence exerted by a factor, and (ri - cj) represents the vertical axis (y-axis) and the degree of influence of a specific driver on the other drivers.

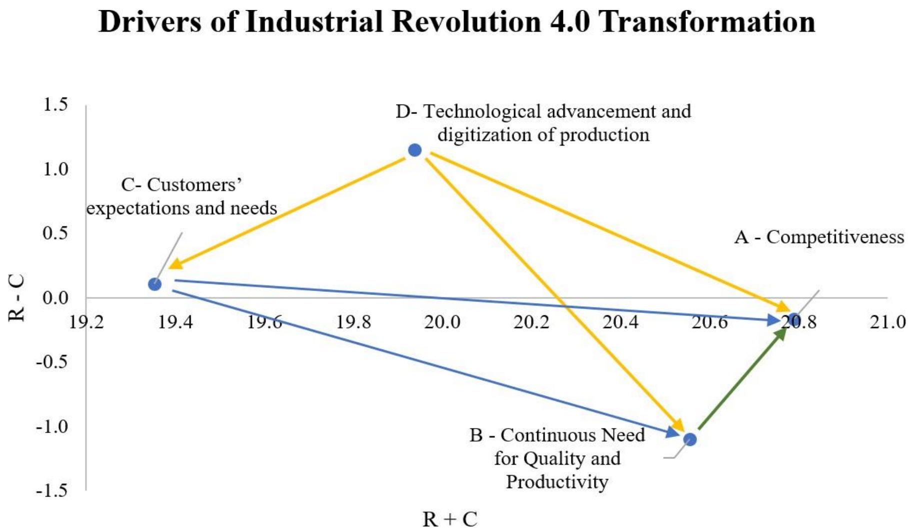

Figure 1. Drivers of Industrial Revolution 4.0 Transformation

According to Table 5 and Figure 1 above, Competitiveness (A) is the most important driver of IR 4.0 transformation in the construction industry because it has the highest value of ri + cj which is 20.7886, whereas Customers' Expectations and Needs (C) is the least important driver. After all, it has the smallest value of ri + cj which is 19.3539. Based on the ri + cj values, the prioritization of the importance of the drivers is Competitiveness (A) > Continuous Need for Quality and Productivity (B) > Technological Advancement and Digitization of Production (D) > Customers' Expectations and Needs (C). Moreover, Technological Advancement and Digitization of Production (D) is the most critical factor that has the greatest direct impact on other drivers as it has the highest positive ri - cj value while Continuous Need for Quality and Productivity (B) is largely influenced by other factors due to it has the lowest negative ri - cj value.

Applying DEMATEL method to the Barriers of IR 4.0 transformation in the construction industry.

Similarly, experts' responses were analysed accordingly. DEMATEL method with similar steps (Step 1-Step 5) was applied accordingly on the barriers (stipulated in Table 6). The average matrix was then calculated (Table 7), normalized (Table 8), and the Total Relation Matrix was derived (Table 9). Subsequently, it leads to the calculation of Sum of Rows and Columns of Matrix T (Table 10). To continue with the depiction of barriers to IR 4.0 transformation in the construction industry, Table 6 highlights seven important barriers for the purpose of DEMATEL pairwise rating process.

Table 6. List of Barriers of Industrial Revolution 4.0 Transformation in Construction Industry

Barriers	Barriers of Industrial Revolution 4.0 Transformation
J	Lack of Employees Acceptance
K	Lack of Financial Resources
L	Lack of Expertise
M	Lack of Data Privacy and Security
N	Lack of Awareness of Industrial Revolution 4.0
O	Inadequate Technologies and Facilities
P	Incompatibility of Innovations

Equation 1 was used to calculate the average matrix Z (barriers vs barriers) based on the ratingsprovided by the 17 experts, which is displayed in Table 7 below.

Table 7. Industrial Average Matrix Z (Barriers vs Barriers)

Barriers	J	K	L	M	N	O	P	SUM
J	0	2.8824	3.2353	1.6471	3.2941	3.1765	2.7059	16.9412
K	2.5294	0	3.1176	2.4118	3.2353	3.5294	3.4706	18.2941
L	3.1176	2.1765	0	1.8824	2.5294	1.8824	3.1176	14.7059
M	1.5294	2.1176	2.4706	0	2.7647	1.5882	3.2941	13.7647
N	3.2941	3.0588	2.9412	2.0588	0	3.2353	3.2353	17.8235
O	1.9412	3.1765	2.5882	2.7059	3.2941	0	3.3529	17.0588
P	3.1765	3.2353	2.1176	2.7647	3.1176	3.1765	0	17.5882
SUM	15.5882	16.6471	16.4706	13.4706	18.2353	16.5882	**19.1765**	

As shown in Table 7, the value 19.1765 was chosen to normalize Matrix Z, which leads to the formulation of Matrix D, with Equation (2) and Equation (3). The normalized initial direct-relation matrix D (Barriers vs Barriers) is shown in Table 8 below:

Table 8. Normalized Direct-Relation Matrix D (Barriers vs Barriers)

Barriers	J	K	L	M	N	O	P
J	0	0.1503	0.1687	0.0859	0.1718	0.1656	0.1411
K	0.1319	0	0.1626	0.1258	0.1687	0.1840	0.1810
L	0.1626	0.1135	0	0.0982	0.1319	0.0982	0.1626
M	0.0798	0.1104	0.1288	0	0.1442	0.0828	0.1718
N	0.1718	0.1595	0.1534	0.1074	0	0.1687	0.1687
O	0.1012	0.1656	0.1350	0.1411	0.1718	0	0.1748
P	0.1656	0.1687	0.1104	0.1442	0.1626	0.1656	0

By applying Equation (4), the total relation matrix T (Barriers vs Barriers) is portrayed in Table 9 below:

Table 9. Total Relation Matrix T (Barriers vs Barriers)

Barriers	J	K	L	M	N	O	P
J	0.8318	1.0056	1.0017	0.8015	1.0863	1.0191	1.1025
K	1.0016	0.9325	1.0518	0.8817	1.1458	1.0895	1.1973
L	0.8733	0.8726	0.7542	0.7243	0.9439	0.8624	1.0008
M	0.7635	0.8220	0.8202	0.5971	0.9013	0.8010	0.9563
N	1.0147	1.0518	1.0278	0.8510	0.9819	1.0606	1.1666
O	0.9256	1.0195	0.9767	0.8487	1.0888	0.8783	1.1318
P	0.9972	1.0473	0.9842	0.8707	1.1100	1.0469	1.0102

By using Equations (5) and (6), the sums of rows and columns of Matrix T (Strategies vs Strategies) are calculated and illustrated in Table 10.

Table 10. Sum of Rows and Columns of Matrix T (Drivers vs Drivers)

Barriers	SUM R	SUM C	R+C	R-C
J	6.8485	6.4077	13.2562	0.4408
K	7.3002	6.7513	14.0515	0.5488
L	6.0314	6.6166	12.6479	-0.5852
M	5.6615	5.5749	11.2364	0.0866
N	7.1544	7.2580	14.4124	-0.1036
O	6.8695	6.7579	13.6274	0.1116
P	7.0665	7.5655	14.6320	-0.4990

With reference to Total Relation Matrix T (Table 9), the threshold value α was calculated using Equation (7), and the threshold value was recorded as α =0.9578. Based on Table 10, a directed graph (digraph) was made to show how one component affects the others. As shown in Figure 2 below, it was very clear how each barrier connected to the others. The data set is mapped to create the causal relationship diagram, where the circle shape is the causal group and the rectangular shape is the effect group, in order to reduce the complexity of the digraph into a more straightforward type of figure. The link between the solid lines is unidirectional, but that between the two dotted lines is bidirectional.

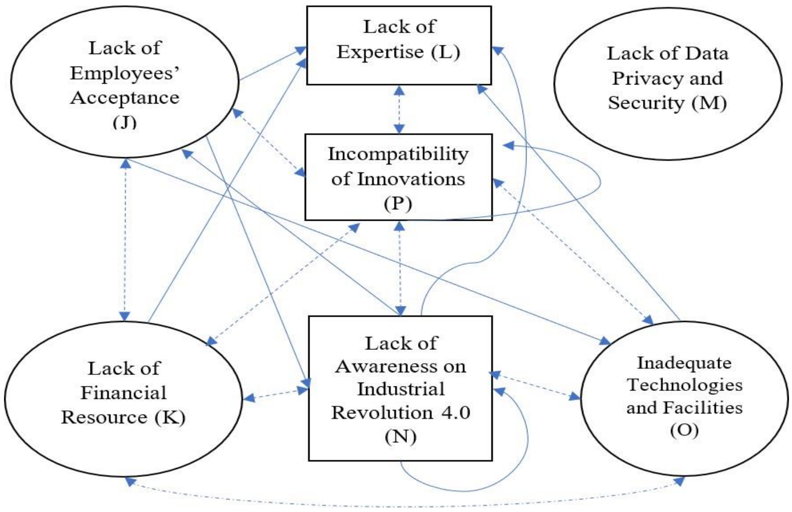

Figure 2. Barriers of Industrial Revolution 4.0 Transformation

Table 10 and Figure 2 show that Incompatibility of Innovations (P), which has the highest ri + cj value of 14.6320, is the most significant barrier to Industrial Revolution 4.0 transformation in the construction industry, while Lack of Awareness of Industrial Revolution 4.0 (N), which has the lowest ri + cj value, is the least significant barrier in this study (11.2364). According to the ascending order of ri + cj values shown in Table 10, the importance of barriers can be arranged in the following order: Incompatibility of Innovations (P) > Lack of Awareness of Industrial Revolution 4.0 (N) > Lack of Financial Resources (K) > Inadequate Technologies and Facilities (O), Lack of Employees' Acceptances (J) > Lack of Expertise (L) > and Lack of Data Privacy and Security (M).

Based on the ri - cj values, the barriers are then separated into causal group and effect group. The barrier elements in this study are Incomplete and Inadequate Technologies and Facilities (O), Lack of Financial Resources (K), Lack of Data Privacy and Security (M), and Lack of Employees' Acceptance (J), with positive ri - cj values of 0.4408, 0.5488, 0.0866, and 0.1116, respectively. According to the findings, the most significant barrier among the others is the Lack of Financial Resources (K). With ri - cj values of -0.5852, -0.1036 and -0.4990, respectively, the remaining impediments, including Lack of Expertise (L), Lack of Awareness on Industrial Revolution 4.0 (N), and Incompatibility of Innovations (P), are categorised into the effect group. The findings indicate that the barrier influenced the most by other barriers is Lack of Expertise (L), which has the lowest negative ri - cj value (-0.5852).

DISCUSSION

Comparing Competitiveness (A) to the other three drivers, the study found that it is the most vital or significant driver of the Industrial Revolution 4.0 transition in the construction industry since it has the greatest value of ri + cj. For an organisation to be competitive, it is necessary to look ahead, integrate technical advancements, and implement the Industrial Revolution 4.0. Substantial efforts are needed to enhance the competitiveness of organizations through converged acceptance of technologies such as smart factories, big data, and artificial intelligence (AI) (Chung, Oh et al. 2022).

Additionally, Customers' Expectations and Needs (C) is the least crucial or significant driver because it has the lowest value of ri + cj. This is due to how quickly customer demands and expectations are changing, which makes this driver less important. For instance, because customers frequently request new products, the lifespan of a product is significantly shortened; as a result, new products and the technology required to make them must evolve. Adaptation to changing conditions is foreseen to happen in most institutions and organizations (Ashaari, Singh et al., 2021).

The study also demonstrates that the other three drivers—Competitiveness (A), Continuous need for quality and productivity (B), and Customers' expectations and needs (C)— are most directly impacted by Technological advancement and digitization of production (D). The Internet of Things (IoT), big data, augmented reality, and other key and advanced technologies for Industrial Revolution 4.0 make it crucial that technological advancement and digitization of production (D) serve as a driver in the transformation of Industrial Revolution

4.0 in the construction industry and have an impact on all other drivers. The Industrial Revolution, which gave rise to several innovations, involved gradual advances in science and technology that made it possible to produce goods and services more efficiently by machine than by hand (David et al. 2022).

Due to their negative ri - cj values, Competitiveness (A) and continuous need for quality and productivity (B) belong to the effect group. As a result, these drivers are susceptible to be influenced by other drivers, particularly Continuous demand need for quality and productivity (B), which has the lowest ri - cj value of all the drivers. Competitiveness (A), Customers' Expectations and Needs (C), and Technological Advancement and Digitization of Production

(D) all have a direct impact on the Continuous Need for Quality and Productivity (B), which also means that all other factors, such as digital technologies and customers' needs, are linked to quality and productivity in the construction industry. Products or services may incorporate embedded geolocation or networking technology with the potential for remote quality monitoring (Castelo-Branco et al. 2022).

When it comes to major obstacles, Incompatibility of Innovations (P) is the most important one for the Industrial Revolution 4.0 transformation in the construction industry because many construction businesses and organizations are currently dealing with technological difficulties and will need to put in a lot of work to get past this obstacle in the future. The least significant or critical barrier is the Lack of Data Privacy and Security (M). This is owing to the fact that many small businesses lack the means and expertise necessary to implement advanced data privacy and security technologies, such as the Internet of Things (IoT) or cyber-physical systems (CPS). As a result, less attention is paid to this barrier. Industrial Revolution 4.0 will gradually increase the need for data privacy and security in order to strengthen the protection of data as well as information, despite the fact that businesses currently place less emphasis on this obstacle. Thus, in order to keep up with the times, construction businesses still need to go beyond the issue or barrier of a lack of data privacy and security. Ensuring data privacy and preventing product counterfeiting and intellectual property theft are the hallmarks of good data integration, management and protection functions (Peerally et al. 2022).

The findings show that Lack of Employees' Acceptance (J), Lack of Financial Resources (K), Lack of Data Privacy and Security (M) and Inadequate Technologies and Facilities (O) belong to the causative group as they have positive ri - cj values. According to the results, Lack of Financial Resources (K) directly affects the other barriers such as Lack of Employees' Acceptance (J), Lack of Expertise (L), Lack of Awareness of Industrial Revolution

4.0 (N), Inadequate Technologies and Facilities (O) and Trouble in Innovation and Incompatibility of Innovations (P). Therefore, it implies that the biggest barrier to the construction industry's transition to the Industrial Revolution 4.0 will be a lack of financial resources, which will also have an impact on a number of other barriers. To ensure technology sustainability, the pitfall of limited financial resources must be avoided (David et al. 2022).

Next, Lack of Financial Resources (K), Lack of Expertise (L), Lack of Awareness of Industrial Revolution 4.0 (N), Inadequate Technologies and Facilities (O), and Incompatibility of Innovations (P) are the other barriers, with Lack of Employees' Acceptance (J) having the second greatest direct impact on them. Because employees' perceptions or attitudes play a significant role when businesses decide to adopt or implement new business plans and digital technologies, their acceptance can readily affect the other barriers. Companies must therefore get beyond this barrier if they want to execute their new business plans or Industry 4.0 technology successfully.

In addition, because they have negative ri - cj values, Human Resource Development (L), Lack of Awareness of Industrial Revolution 4.0 (N), and Difficulty in Innovation and Introducing New Products and Services (P) belong to the effect group. All of these barriers are susceptible to influence from other barriers, particularly Human Resource Development (L),

which has the lowest ri-cj values. Lack of Employees' Acceptance (J), Lack of Financial Resources (K), Lack of Awareness of Industrial Revolution 4.0 (N), Inadequate Technologies and Facilities (O), and Incompatibility of Innovations (P) have a direct influence on Lack of Expertise (L), which means that many other barriers have linked with human resource development so that employees must improve skills and techniques themselves primarily relates to smart technologies.

CONCLUSION AND RECOMMENDATION

The majority of earlier studies conducted by other researchers simply have an emphasis on identifying the factors that are causing or obstructing IR 4.0 implementation in the construction industry. The drivers and barriers that are connected to the IR 4.0 transition in the construction industry are investigated less frequently, including their direct, indirect, and interdependent relationships. The topic of the interaction between the drivers and barriers of the IR 4.0 transformation in the construction industry using the DEMATEL technique is also not covered in any research studies. As a result, this research study is able to increase the number of IR 4.0 applications in the construction industry by fostering a better knowledge of the interactions between drivers and barriers theories and empirical findings.

Purposive sampling was used to select 17 experts with a minimum of six years of building industry experience in order to disseminate a survey questionnaire that complies with DEMATEL algorithm in order to accomplish the goals of this research study. By employing the DEMATEL technique, this research study assessed the interactions between the barriers and drivers of the IR 4.0 transformation in the construction industry in the form of directed graphs (Digraph).

The findings indicate that the most significant driver of IR 4.0 transformation in the construction industry is Competitiveness (A). Therefore, in order for businesses to increase their level of competitiveness in the global market, they must start to decide how to transition from traditional production processes to the new IR 4.0 paradigm. Additionally, in order to make a difference, construction businesses need to strengthen their competitive forces, such as by becoming more proficient in technology and strategies. By leveraging IR 4.0 technology to develop goods and services that can satisfy both domestic and international market demands, the construction industry as a whole can boost national income and create job possibilities for the unemployed.

In addition, this research study found that the biggest obstacle to IR 4.0 transformation in the construction industry is difficulty innovating and delivering new products and services (incompatibility of innovations). Many businesses that are facing technological difficulties may struggle to innovate and launch new goods and services. For instance, different levels of autonomous systems and operations, as well as different lifecycle levels of intelligent machines implemented by businesses, will result in the replacement of machine parts at various times, while the remainder will require various levels of technological retrofitting. In order to solve these issues, businesses must now give greater thought to the complexity of their current organizational structures and operational processes.

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REFERENCES

Ashaari, M. A., K. S. D. Singh, G. A. Abbasi, A. Amran and F. J. Liebana-Cabanillas. (2021). Big data analytics capability for improved performance of higher education institutions in the Era of IR 4.0: A multi-analytical SEM & ANN perspective. Technological Forecasting and Social Change, 173, 121119.

Alaloul WS, Liew MS, Zawawi NA, Kennedy IB. (2020). Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. Ain Shams Engineering Journal, 11(1), 225–230.

Arnold C, Veile JW, Voigt KI. (2018). What drives industry 4.0 adoption? An examination of technological, organizational, and environmental determinants. Towards Sustainable Technologies and Innovation - Proceedings of the 27th Annual Conference of the International Association for Management of Technology, IAMOT 2018.

Bal HÇ, Erkan Ç. (2019). Industry 4.0 and Competitiveness. Procedia Computer Science, 158, 625–631.

Boadu EF, Wang CC, Sunindijo RY. (2020). Characteristics of the Construction Industry in Developing Countries and Its Implications for Health and Safety: An Exploratory Study in Ghana. International Journal of Environmental Research and Public Health, 17 (11), 4110.

Brettel M, Friederichsen N, Keller M, Rosenberg M. (2014). How Virtualization, Decentralization and Network Building Change the Manufacturing landscape: An Industry 4.0 Perspective. International Journal of Information and Communication Engineering, 8 (1), 37-44.

Castelo-Branco, I., T. Oliveira, P. Simões-Coelho, J. Portugal and I. Filipe. (2022). Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain. Computers in Industry, 138, 103639.

Chung, J.-E., S.-G. Oh and H.-C. Moon . (2022). What drives SMEs to adopt smart technologies in Korea? Focusing on technological factors. Technology in Society, 71, 102109.

Craveiro F, Duarte JP, Bartolo H, Bartolo PJ. (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. Automation in Construction, 103, 251–267.

Dallasega P, Rauch E, Linder C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. Computers in Industry, 99, 205–225.

David, L. O., N. I. Nwulu, C. O. Aigbavboa and O. O. Adepoju. (2022). Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis. Journal of Cleaner Production, 363: 132522.

Enzmann, P. and M. Moesli. (2022). Seizing opportunities: ASEAN country cluster readiness in light of the fourth industrial revolution. Asia and the Global Economy, 2 (1), 100021.

Erol S, Jäger A, Hold P, Ott K, Sihn W. (2016). Tangible Industry 4.0: a scenario-based approach to learning for the future of production. Procedia CIRP, 54, 13–18.

Fettermann DC, Cavalcante CG, Almeida TD, Tortorella GL. (2018). How does Industry 4.0 contribute to operations management? Journal of Industrial and Production Engineering, 35(4), 255–268.

Gehrke L, Rule D, Bellmann C, Moore P, Siemes S, Singh L, Standley M, Dawood D, Kulik J, Kühn AT. (2015). A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective. ASME American Society of Mechanical Engineers, VDI The Association of German Engineers Publications, 1-26.

Georg A, Niklas G, Florian S, Wolfram R. (2015). Industry 4.0 - Background Paper on the pilot project Industry 4.0: Foresight & Technology Assessment on the social dimension of the next industrial revolution.

Glova J, Sabol T, Vajda V. (2014). Business Models for the Internet of Things Environment.

Procedia Economics and Finance, 15, 1122–1129.

Herrmann C, Schmidt C, Kurle D, Blume S, Thiede S. (2014). Sustainability in Manufacturing and Factories of the Future. International Journal of Precision Engineering and Manufacturing-Green Technology. 1(4), 283–292.

Horváth D, Szabó RZ. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? Technological Forecasting and Social Change, 146, 119–132.

Kaushik S, Somvir. (2015). DEMATEL : A Methodology for Research in Library and Information Science. International Journal of Librarianship and Administration, 6(2), 179–185. [accessed 2021 19 December]. http://www.ripublication.com.

Li J, Yang H. (2017). A Research on Development of Construction Industrialization Based on BIM Technology under the Background of Industry 4.0. MATEC Web of Conferences. 100, 02046.

Ling YM, Abdul Hamid NA, Chuan LT. (2020). Is Malaysia ready for Industry 4.0? Issues and Challenges in Manufacturing Industry. International Journal of Integrated Engineering. 12 (7), 134–150.

Livotov P, Chandra Sekaran AP, Mas'udah, Law R, Reay D, Sarsenova A, Sayyareh S. (2019). Eco-innovation in process engineering: Contradictions, inventive principles and methods. Thermal Science and Engineering Progress, 9, 52–65.

Low SP, Gao S, Ng EW. (2019). Future-ready project and facility management graduates in Singapore for industry 4.0. Engineering, Construction and Architectural Management, 28(1), 270–290.

Müller JM, Buliga O, Voigt K-I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and Social Change, 132(1), 2–17.

Müller JM, Kiel D, Voigt K-I. (2018). What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. Sustainability, 10(1), 247.

Nagy J, Oláh J, Erdei E, Máté D, Popp J. (2018). The Role and Impact of Industry 4.0 and the Internet of Things on the Business Strategy of the Value Chain—The Case of Hungary. Sustainability. 10(10), 3491.

Newman C, Edwards D, Martek I, Lai J, Thwala WD, Rillie I. (2020). Industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study. Smart and Sustainable Built Environment. 10 (4):557–580.

Nyberg E, Nilsen S. (2016). The adoption of Industry 4.0 technologies in manufacturing – a multiple case study. Master of Science Thesis. KTH Industrial Engineering and management.

Pereira AC, Romero F. (2017). A review of the meanings and the implications of the Industry 4.0 concept. Procedia Manufacturing, 13(1), 1206–1214.

Pheng LS, Hou LS. (2019). Construction Quality and the Economy. Singapore: Springer Nature Singapore Pte Ltd.

Prassida, G. F. and U. Asfari. (2022). A conceptual model for the acceptance of collaborative robots in industry 5.0. Procedia Computer Science, 197(1), 61-67.

Prause M. (2019). Challenges of Industry 4.0 Technology Adoption for SMEs: The Case of Japan. Sustainability, 11(20), 5807.

Peerally, J. A., F. Santiago, C. De Fuentes and S. Moghavvemi. (2022). Towards a firm-level technological capability framework to endorse and actualize the Fourth Industrial Revolution in developing countries. Research Policy, 51(10), 104563

Qian F, Zhong W, Du W. (2017). Fundamental Theories and Key Technologies for Smart and Optimal Manufacturing in the Process Industry. Engineering, 3(2), 154–160.

Rüßmann, M., Lorenz, M., Gerbert, P.D., Waldner, M., Justus, J., Engel, P., & Harnisch, M.J. (2016). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries April 09.

Schumacher A, Erol S, Sihn W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Procedia CIRP, 52, 161–166.

Tupa J, Simota J, Steiner F. (2017). Aspects of risk management implementation for Industry 4.0. Procedia Manufacturing, 1223–1230.

Zabidin NS, Belayutham S, Ibrahim CKIC. (2019). Industrial Revolution (IR) 4 . 0 in Construction Engineering Education : A Bibliometric Analysis. Journal of Building Performance. 10 (2), 21–27

CONFLICT OF INTEREST

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