The Key Strategies to Implement Circular Economy in Building Projects—A Case Study of Taiwan

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Abstract: The building industry is blamed for consuming enormous natural resources and creating massive solid waste worldwide. In response to this, the concept of circular economy (CE) has gained much attention in the sector in recent years. Many pilot building projects that implemented CE concepts started to appear around the world, including Taiwan. However, compared with the pilot projects in the Netherlands, which are regarded as the pioneer ones by international society, many CE-related practices are not implemented in pilot cases in Taiwan. To assist future project stakeholders to recognize what the key CE-related practices are and how they could be implemented in their building projects in Taiwan, this study has conducted a series of case studies of Dutch and Taiwanese pilot projects and semi-structured interviews with key project stakeholders of Taiwanese pilot projects. Thirty key CE-related practices are identified via case studies, along with their related 5R principles (Rethink, Reduce, Reuse, Repair, Recycle) and project phases. Suggestion on CE-related practices, their 5R principles, project items, and phases to implement in building projects in Taiwan is also proposed while discussion on differences between two countries' pilot projects is presented.

Keywords: circular economy in construction; strategic implementation; 5R principles

1. Introduction

Building industry consumes enormous natural resources and creates massive solid waste around the world. For example, according to the new Circular Economy Action Plan released by European Commission, it accounts for about 50% of all extracted materials and over 35% of the total waste generation in Europe [1]. It is also responsible for about 50% of raw materials and 40% of solid waste in the Netherlands [2]. In Taiwan, it has used about 25 million tons of raw materials and generated nearly 2 million tons solid waste yearly based on the estimation of the Environmental Protection Administration, placing much pressure on this small island country that lacks many natural resources and facilities to deal with construction and demolition waste [3].

To tackle the challenging environmental problems that the building industry has brought, the concept of circular economy (CE) has gained its popularity by public and private sectors around the globe. For instance, European Commission will launch a new comprehensive Strategy for a Sustainable Built Environment in 2021, integrating CE principles in its policies including addressing the sustainability performance of construction products, improving the durability and adaptability of built assets, etc. [1]. The Government of the Netherlands has proposed a roadmap to implement CE in its construction industry in 2016, executing actions including adding substance to innovative and circular construction projects, developing a circular construction assessment method, etc. [2]. The government of Taiwan has also highlighted construction industry as one of its major focus in its CE implementation roadmap in 2018, promoting measures including enhancing front-end classification and recycling efficiency, encouraging partnerships and collaborations between different sectors, etc. [4]. However, CE implementation in the building industry globally is

just at its initial stage, facing many barriers such as unproven business cases of requiring manufacturers to be responsible for their products once they reach their end of life [5].

Meanwhile, several CE-focused pilot building projects have started to appear around the world to test and demonstrate the robustness of CE concepts for building [2,6–8]. For example, Park20|20 in the northern Netherlands is famous for implementing the C2C principles in a holistic and multilevel way since the 2010s. The Amsterdam Schiphol airport is recognized for adopting new CE-related business models such as product as a service for their lighting system since 2015. The new pavilion built by the Dutch bank ABN AMRO in 2017 is noted for its innovative financial model. The Dutch pilot projects are regarded as the pioneer ones by the international society [2,9]. However, limited research has conducted case study on these cases [6], and none has delivered overview and comparison of their adopted CE-related practices between these cases in a systematic way, hindering the international society to learn and utilize the CE implementation experience from these cases comprehensively.

Meanwhile, following the global trend of CE adoption, several building projects in Taiwan are also proposed to implement CE principles in recent years. Many of them are public housing projects, highlighting the CE-related practices including modular and flexible units, recycled materials and sharing space, etc. However, compared with the pilot cases in the Netherlands, many CE-related practices seem to not be implemented yet in ones in Taiwan [10]. Further investigation on the differences between the two countries' pilot cases and the reasons behind them are critical for Taiwan's building industry to propose suitable CE implementation strategies and international society to see how CE concepts are implemented in building projects in different countries.

The main objectives of this study are to identify the key CE-related practices from the Dutch and Taiwanese pilot building projects, the differences between them and the reasons behind those, and to propose an implementation framework for building projects in Taiwan. The key research questions include: What are the key CE-related practices implemented in these pilot projects and how to understand them? What are the different practices adopted in these projects and the reasons behind them? How can the building industry in Taiwan implement the practices learned from the Dutch cases?

To answer these research questions, this study carried out a series of case studies of CE-focused pilot projects both in the Netherlands and Taiwan and semi-structured interviews with key project stakeholders of Taiwan projects. Thirty key CE-related practices are identified in five pilot projects and noted. Their related 5R principles (Rethink, Reduce, Reuse, Repair, Recycle), project phases, items, and implementation time are also noted by the authors and interviewees. Suggestions on implementing CE in building projects in Taiwan are proposed, and discussion on difference between practices in the Netherlands and Taiwan are also made in this study.

The key contributions of this study include presenting a case study of CE-focused pilot building projects in the Netherlands and Taiwan in a systematic way by marking their CE-related practices, related 5R principles, project phases, and items for international society to see how CE concepts are implemented at project level in different countries. Furthermore, based upon the identification of these key CE-related practices and other essential information to consider before implementation in building projects in Taiwan (i.e., related project phases, items, 5R principles, and implementation time), an implementation framework is proposed for future Taiwanese building project stakeholders. For countries whose building industry is at the similar CE implementation stage as Taiwan, similar methods can be applied for them to identify suitable strategies to implement these CE practices.

This paper is structured by the following sections: in Section 2, literature review on circular economy, its concepts, and research for building industry is presented, along with the 5R principles and its applications in building projects, and the CE-focused pilot building projects both in the Netherlands and Taiwan. Section 3 reveals the methodology adopted in this study to deliver a series of case studies of the chosen Dutch and Taiwanese pilot

projects and interviews with key stakeholders in Taiwanese pilot projects. Section 4 presents the results gained by case study and interviews, which are the identified key CE-related practices in pilot projects, their related 5R principles, project phases and implementation time for building projects in Taiwan. Section 5 delivers discussions on research results by comparing differences between two countries' pilot projects and by organizing the CE-related practices with their related project categories and items. An implementation framework is developed based upon these discussions and contained in Section 5. In the end, Section 6 summarizes the conclusion and limitation of this study and some ideas on future research directions.

2. Literature Review

2.1. Circular Economy, Its Concepts, and Its Research for Building Industry

Since the Second Industrial Revolution more than a century ago, mass production and rapid economic growth have been seen in human history, as well as the enormous resource harvesting and severe environmental pollution. This is resulted from the current economic model, known as a "linear model," which is mainly composed of three parts, "take-make-waste," referring to the linear process of modern product life cycle, from harvest, manufacture, usage, then to disposal [11]. In response to this situation, the concept of "circular economy (CE)" has arisen since half a century ago and gained tremendous attention in the past half decade [12]. In contrast to linear models, CE creates loops in the product life cycle to retain the value of resources (i.e., products, components, materials) in every stage and thus avoiding generating waste [11].

To implement a circular economy, many frameworks and approaches have been proposed. Two of the most referred frameworks are ReSOLVE [13] and the "butterfly diagram" [11] proposed by Ellen MacArthur Foundation. The former one aims to assist businesses and countries in generating circular strategies, while the latter one portraits various approaches of CE in both biological and technological systems, guiding researchers and practitioners to understand CE. Similar to the butterfly diagram, the R-Imperatives are also widely used for conceptualizing CE and systematic thinking [14]. Among them, even though the 3R framework (reduce, reuse, recycle) seems to be the most prominent one [14], 5R is the most utilized one in CE-related literature [15]. This is recognizable, since 3R is obviously insufficient in representing various loops that CE emphasizes, while 9R is detailed, specific, and might not be applicable to different kinds of industries [16]. In this study, the 5R framework is chosen to understand CE concepts and their practices in building industry.

The trend of CE has also aroused much attention from the building industry around the world. Research on this theme is growing rapidly, with the number of publications doubling each year from 2016 to 2019 [17]. Among them, research on recycled/reusable materials and circular transition are the major parts, followed by tools and assessments to support circular buildings, CE-related product and building design, and stock and flow analysis of resources and materials [17]. Several research have summarized CE-related practices for building projects throughout life cycle through literature review [18,19]. However, study on CE-related practices on pilot projects is yet to be found. Some case studies on pilot projects have been conducted in countries like the Netherlands and Taiwan [6,9,10], yet their focuses are not on their CE-related practices, but on developing collaboration tools for stakeholders [6], exploring successful paths of knowledge transition of CE [9], and disclosing current status and barriers of the building industry [10].

2.2. The 5R Principles and Its Applications in Building Projects

Several research have categorized CE-related practices by different phases in building life cycle [17,18] and ReSOLVE framework proposed by Ellen MacArthur Foundation [20]. However, study on utilizing R-Imperatives to review CE-related practices in building projects are yet to be seen. To systematically understand CE-related practices in building projects, the 5R framework is utilized in this study. As mentioned in Reike et al.'s work [15],

there is no consensus on what R-Imperatives stand for, even the most prominent 3R framework. The combinations of R-Imperatives are chosen according to the application scenarios and best interests of applicants. In this research, the 5R principles set to be utilized are Rethink, Reduce, Reuse, Repair and Recycle, since they are identified to be more relevant to building projects [14]. The definitions, objectives, and their applications in building projects of these 5R principles are shown in Table 1.

Table 1. Definitions, objectives of 5R principles and their applications in building industry (summarized by the authors).

5R Principles	Definition	Objective	Examples in Building Industry
Rethink	• To make a product use-intensive (e.g., by sharing products or by creating mufti-functional products) [21] • To replace parts as a service [22] • To recreate ideas, processes, dynamics of a product [23]	To achieve maximum resource efficiency through innovative model [23]	• Sharing space, sharing ownership • Pay per lux or pay per scan [24] • Material passport [25]
Reduce	• To use fewer natural resources, and therefore fewer inputs of energy, raw materials, and waste [23] • To dematerialize (i.e., to substitute a product by a nonmaterial alternative with the same utility for users) [15]	To achieve minimum resource usage through production and consumption [23]	• Energy-saving and water-saving system • Lightweight design [26] • Prefabricated module [27]
Reuse	• To use a product again while retaining it function and identity [23]	To achieve maximum usage of a product through relocation or resell [23]	• Reuse of structural component [28] • Material bank [29]
Repair	• To repair and maintain a product to be used with its original function [23]	To achieve maximum lifespan of a product through repair and maintenance [23]	• Design for disassembly [30] • Smart facility management system [31]
Recycle	• To process materials to obtain the same or quality of materials (e.g., shredding, melting) [23]	To achieve minimum usage of newly mining resources by reprocessing materials [15]	• Electric arc furnace steel, fly ash cement • Cradle to cradle design [32]

2.3. Circular Economy Focused Pilot Building Projects

The Netherlands is considered to be a pioneering country in implementing a circular economy. Its government proposed an ambitious plan in 2016, aiming to achieve a circular economy by 2050 in its five major industries, including construction [2]. Several pilot projects in the Netherlands also become well known by the international society for case study [18]. In this study, three Dutch pilot projects are chosen for case study because of their wide variety of CE-related practices: Park20|20, Venlo City Hall, ABN AMRO CIRCL.

Here are some brief introductions of these three Dutch pilot projects. First of all, Park 20|20, adjacent to Schiphol Airport in the northern Netherlands, is the first full-service Cradle to Cradle (C2C) office park in the world, synthesizing access and mobility, passive design, and integrated energy, water and waste management systems etc. Since 2007, Delta Development Group and William McDonough + Partners have been working closely together to create a new model of sustainable development that implements the C2C principles in a holistic and multilevel way, and until now, it is still a successful case to which many researchers refer [33]. Second, Venlo City Hall, located in the southeast of

the Netherlands, is another famous C2C building project, emphasizing a comfortable and healthy working environment with innovative sustainability. Built in 2016, this new city hall has become a sign of excellent service to residents and businesses, exuding the important features of municipal organization: open, transparent, and accessible [34]. Last but not the least, ABN AMRO CIRCL, set in the heart of Amsterdam's Zuidas business district, is a multipurpose circular pavilion, centering on high-quality recycling of materials, energy-neutral consumption, and minimum of waste. Open to the public in 2017, Circl represents ABN AMRO's sustainability ambitions and its commitment to finance sustainable homes and offices in order to contribute to a future-proof society [35]. A brief comparison of these three cases are shown in Table 2 to have more understanding on their attributes.

Table 2. Basic information of circular economy (CE)-focused pilot projects in the Netherlands.

	Park20|20 [33] [1]	Venlo City Hall [34] [1]	ABN AMRO CIRCL [35] [1]
Picture			
Use type	Commercial (office)	Specialty (government)	Specialty (pavilion)
Built year	2012~[2]	2016	2017
Level	NA	11 floors	2 floors
Site area	114,000 m^2	27,700 m^2	NA
Floor area	NA	13,500 m^2	3300 m^2

[1] Refs [33–35] are sources of pictures and numbers in Table 2. [2] This development project is still on going.

In this study, two pilot cases in Taiwan are chosen to reflect the current implementation status of CE in building projects in the country because of their more mature project phases. The first project is known as Shalun circular housing project (also known as Taisugar's circular village) in southern Taiwan. Proposed by Taiwan Sugar Corporation and designed by Bio-architecture Formosana, this project introduced many CE concepts such as flexible configuration and building as materials bank, etc., combined with other features including smart electricity, water network, self-cultivated food, etc. (see Figure 1) [36]. The second project is called Nangang public housing project in Taipei. Proposed by Taipei City Government, this project also integrates many CE concepts such as modular spatial unit planning and product as a service model etc., joined by other practices including smart home appliances and sharing space, etc. (see Figure 1) [37]. More information is conveyed in Table 3 to gain more understanding on these two projects.

Table 3. Basic information of CE-focused pilot projects in Taiwan.

	Shalun Circular Housing [36]	Nangang Public Housing [37]
Picture		
Use type	Residential (apartment)	Residential (apartment)
Current Phase	Construction	Construction
Level	8 floors	26 floors
Site area	13,994 m^2	78,811 m^2
Floor area	28,580 m^2	141,850 m^2

Refs. [36,37] are sources of pictures and numbers in Table 3.
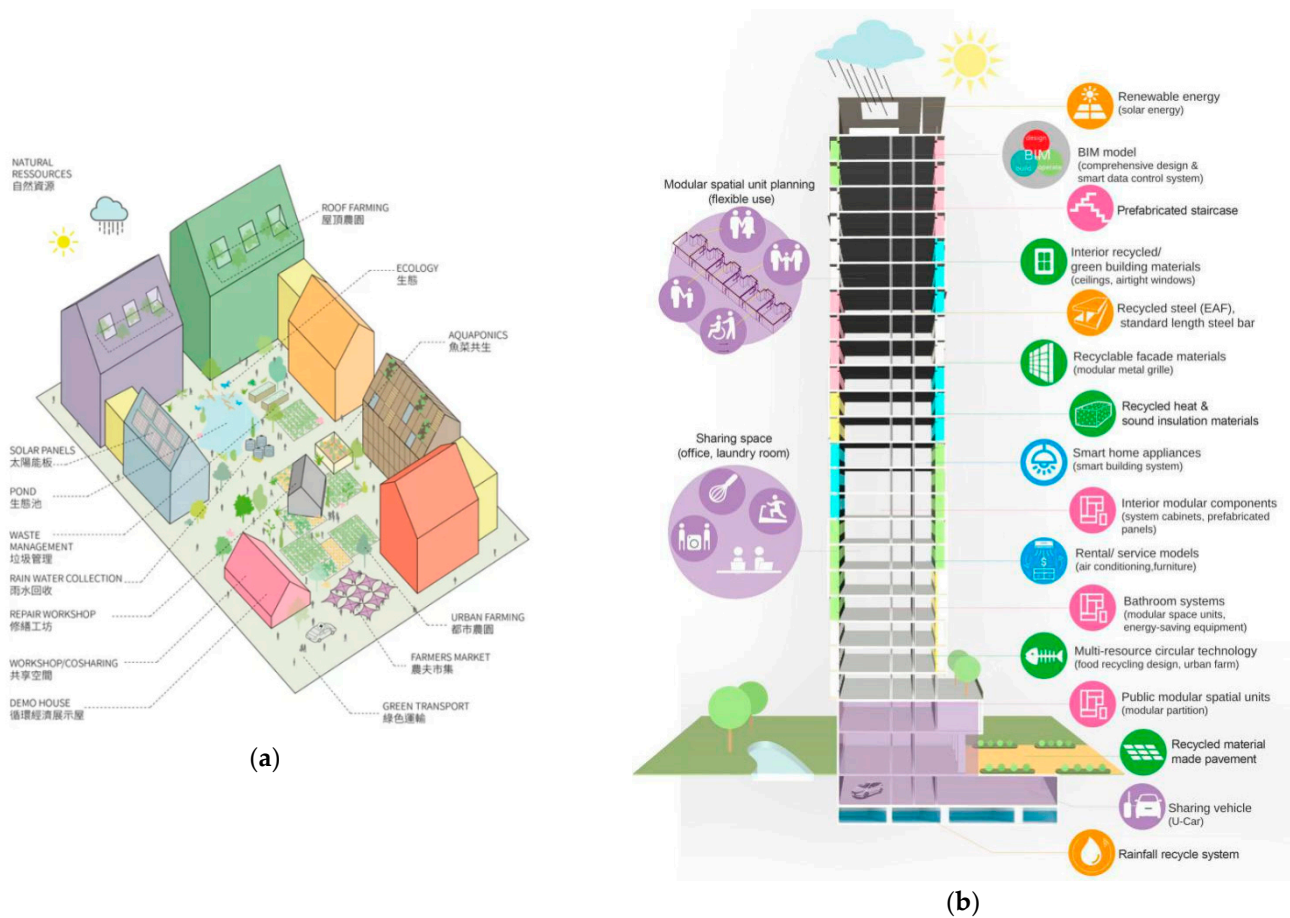
Figure 1. Description on CE-related practice of Taiwanese pilot projects (**a**) Shalun Circular Housing [36]; (**b**) Nangang Public Housing (drawn by the authors).

3. Methodology

The research process of this study is as following (shown as Figure 2): first, the key CE-related practices of the selected three Dutch pilot building projects were identified through reviewing their related literature and publications (shown as Table 4), and noted with related project phases by the authors, along with the related 5R principles (Rethink, Reduce, Reuse, Repair, Recycle) based on definitions identified through literature review of related academic publications (see Section 2.2). A table containing these three sets of information of three Dutch pilot projects was generated. Second, the key CE-related practices of the selected two Taiwanese pilot projects are identified by their key project stakeholders, which are the two interviewees in this study. They were asked to mark the CE-related practices in their projects based upon the table generated in step one. Third, the interviewees were asked to mark the expected implementation time of each key CE-related practice for building projects in Taiwan by short term (i.e., becoming common practice within a five-year time period) or long term (only after a ten-year time period) or both scenario (i.e., being implemented within a five-year time period, but only becoming common practice afterwards). Fourth, the interviewees are asked to discuss the differences of CE-related practices between pilot projects in two countries and the reasons behind them based upon the notation results in previous steps. Information on interviewees are shown in Table 4 and interview questions in Tables 5 and 6.
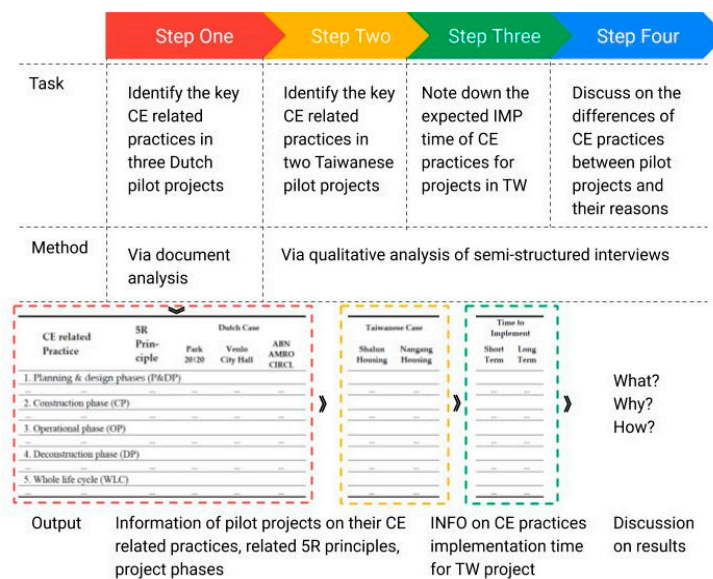
Figure 2. Description on research process (drawn by the authors).

Table 4. Reference of related literature and publications for case study of three Dutch pilot projects.

Project Name	Related Literature & Publications
Park20|20	webpage [33,38], report [39]
Venlo City Hall	webpage [34,40], report [41,42]
ABN AMRO CIRCL	webpage [35], report [43]

Table 5. Basic information of two interviewees.

	Interviewee A	Interviewee B
Project	Shalun Circular Housing	Nangang Public Housing
Role	Principal Architect	Client Representative
Experience	15 years	25 years

Table 6. Basic information of interview questions.

Interview Questions
In your personal point of view,
1. What are the reasons behind different CE related practices adopted between your project and the Dutch pilot ones?
2. What are the important aspects to consider when deciding the CE related practices for adoption for your project?

The research methods adopted in this study can be regarded as two types: document analysis for the proposed research process step one, and qualitative analysis of semi-structured interviews for steps two to four. A cross case analysis was done subsequently based on the document study and the outcomes of the interviews for further research discussion. Semi-structured interview was adopted for it is suitable for interviews with open-ended questions requiring follow-up queries [44]. Similar research methods were adopted for case study of CE implementation in the building sector [6]. These methods belong to the methodology named as "Grounded Theory," which allows theories to emerge from the data collected. It is known as a simultaneous process of collecting and analyzing data by constant comparative analysis [45]. Its main issues regard precision and clarity. To address these issues, this study used qualitative content analysis when explaining results. A similar method was utilized to identify the strategic role of CE in other industries [46,47].

4. Results

Thirty CE-related practices are summarized based on case study of three Dutch pilot projects. To study these practices, they are matched with 5R principles and sorted by different building life cycle: planning & design phase (P & DP), construction phase (CP), operational phase (OP), destruction phase (DP), and whole life cycle (WLC). The majority of practices (16) were implemented in P & DP, while some in CP and OP (5 & 5), and few in DP and across WLC (2 & 2). In P & DP, Rethink and Reduce principles are highlighted, related to 8 and 5 CE-related practices, respectively. Reduce and Recycle principles are more common for practices in CP, while Reuse and Repair are for OP. CE-related practices in DP and WLC are related to more than two 5R principles, indicating their importance and challenge.

CE-related practices of two pilot cases in Taiwan, Shalun and Nangang Housing, are marked by interviewees, which are 24 and 17, respectively. The potential implementation time of these thirty practices for building projects in Taiwan are also noted by interviewees. Many of them (14 out of 30) are expected to be commonly implemented in short term, i.e., within a five-year time period, while some (10) are to be implemented in short term and to be common in long term, i.e., after ten years, and few (6) are to be implemented only long term. These results are shown in Table 7.

Table 7. Identification of CE-related practices of pilot cases in the Netherlands and Taiwan and their potential implementation time for Taiwanese building projects.

	CE Related Practice	5R Principle	Dutch Case			Taiwanese Case		Time to Implement	
			Park 20|20	Venlo City Hall	ABN AMRO CIRCL	Shalun Housing	Nangang Housing	Short Term	Long Term
			1. Planning & design phases (P & DP)						
1	Innovative business model (e.g., material ownership by supplier)	Rethink	●	●	●				▲
2	Innovative financial model (e.g., flexible taxation)	Rethink			●				▲
3	Passive/green/bio-architectural design	Rethink	●	●	●	●	●	▲	
4	People-oriented design (e.g., good indoor environment)	Rethink	●	●	●	●	●	▲	
5	Natural lighting system	Reduce	●	●	●	●	●	▲	
6	Solar energy system	Reduce	●	●	●	●	●	▲	
7	Heat recovery system	Recycle	●	●	●	●	●	▲	
8	Water recycle system	Recycle	●	●	●	●	●	▲	
9	Leftover recycle system	Recycle	●	●	●	●	●	▲	
10	Urban agriculture	Rethink	●	●	●	●	●	▲	
11	Lightweight structure	Reduce	●		●	●	●	▲	
12	Modular unit (e.g., modular partition/exterior wall)	Reuse	●	●	●	●	●	▲	▲
13	Flexible unit (e.g., design for disassembly)	Repair	●	●	●	●		▲	▲
14	CE related certification (products/materials/organization)	Rethink	●	●	●				▲
15	Closed loops (e.g., on-site resource circular flows)	Rethink/Reduce	●	●	●	●		▲	▲
16	Zero waste/zero energy consumption	Rethink/Reduce	●						▲

Table 7. *Cont.*

CE Related Practice	5R Principle	Dutch Case			Taiwanese Case		Time to Implement	
		Park 20|20	Venlo City Hall	ABN AMRO CIRCL	Shalun Housing	Nangang Housing	Short Term	Long Term
2. Construction phase (CP)								
17 Reusing green and healthy materials	Reuse	●	●	●	●	●	▲	
18 Using renewable or recycled materials	Recycle	●	●	●	●	●	▲	
19 Construction waste recycling system	Recycle	●	●	●	●	●	▲	
20 Prefabrication system	Reduce	●		●	●	●	▲	▲
21 3D printing	Rethink/Reduce			●				▲
3. Operational phase (OP)								
22 Lifespan extension (smart maintenance/repair/renewal)	Reduce/Repair	●	●	●	●	●	▲	
24 Building materials/equipment tracking (e.g., QR code)	Rethink/Repair			●	●		▲	▲
23 Sharing space (e.g., co-working space)	Rethink/Reuse	●	●	●	●	●	▲	
25 Sharing ownership (e.g., appliance, vehicle)	Rethink/Reuse	●	●	●	●		▲	▲
26 Exchange platform (e.g., used goods, agricultural products)	Rethink/Reuse			●	●		▲	▲
4. Deconstruction phase (DP)								
27 Quantifying residual value of materials	Rethink/Reuse/Recycle	●	●	●				▲
28 Material bank	Rethink/Reuse/Recycle	●	●	●	●		▲	▲
5. Whole life cycle (WLC)								
29 Product as a service (e.g., lighting, elevator, furniture, appliance)	Rethink/Reduce/Reuse/Repair	●		●	●	●	▲	▲
30 Material passport	Rethink/Reduce/Reuse/Repair/Recycle	●	●	●	●		▲	▲

● is notation for project-related practices while ▲ highlights expected implementation time for practices.

5. Discussion

5.1. Differences between Circular Economy Related Practices in Dutch and Taiwanese Building Projects

Through comparing CE-related practices in Dutch and Taiwanese pilot projects, differences between these two countries are revealed. This is further discussed by highlighting 5R principles of these practices, noting their related project items and excluding the CE-related practices that are common in pilot projects in both countries. As shown as Table 8, many practices of Rethink principles have just started to develop in Taiwan (e.g., product as a service, sharing ownership and material passport), and many are considered to be implemented in ten years' time (e.g., innovative business model and CE-related certification). How key stakeholders as suppliers and policy makers in Taiwan can fasten the implementation of these practices should be investigated in the future. As for the Reduce principle, prefabrication system is still considered to be a CE-related practice that requires a long period of time for common implementation in Taiwan by the interviewees, comparing

to the Dutch case, even though both pilot cases in Taiwan have adopted some prefabrication systems for structural, exterior, and interior engineering. As for the Reuse and Repair principle, modularity and flexibility of units and standardization of size of all building components and products are still challenging for Taiwanese scenarios, according to the interviewees. Lastly, as for the Recycle principle, its related CE practices are all identified as to be implemented commonly in the short term, which is the same as the Dutch scenario shown by its pilot cases.

Table 8. Highlighting of the uncommon CE-related practices in Taiwanese building industry, their related 5R principles and project items.

5R Principle	Category	Item	CE Related Practice	Time to Implement	
				Short Term	**Long Term**
Rethink	MEP	Lighting & HVCA system	Product as a service	▲	▲
	F & A	Furniture & appliance	Product as a service	▲	▲
		Sharing ownership	Vehicle, appliance	▲	▲
		Exchange platform [1]	Used goods, agricultural products	▲	▲
	Other	Building information modeling	Material passport	▲	▲
		3D printing [1]	3D Printing structure, component		▲
		Net zero buildings [1]	Zero waste/energy consumption		▲
		Closed loops	On-site resource circular flows	▲	▲
		CE related certification	BS 8001, Cradle to Cradle, etc.		▲
		Innovative financial models [1]	Flexible taxation, etc.		▲
		Innovative business models	Material ownership by supplier, etc.		▲
Reduce	Structural	Structural system	Prefabricated beam, column, etc.	▲	▲
	Exterior	Exterior system	Prefabricated panel, facade, etc.	▲	▲
	Interior	Interior system	Prefabricated panel, partition, etc.	▲	▲
Reuse	All	Building components, products	Modularization of unit/Standardization of size	▲	▲
	Interior	Spatial units	Modularization of plane	▲	▲
Repair	All	Building components, products	Flexibility of unit	▲	▲
		Building materials & equipment [1]	Maintenance management system with QR Code	▲	▲

[1] The highlighted items are CE-related practices that are not common among three Dutch cases.

5.2. Reflection on Research Results with Working Hypotheses and Past Research

Before interviewing the key project stakeholders of Taiwanese pilot projects, the authors assumed that the 5R principles, project phases, and expected implementation time (i.e., feasibility for implementation) of the identified CE-related practices are three key information to consider for CE implementation for project stakeholders. Based upon interviewees' responses, these information are relevant to their considerations. However, the information on relevant project items for CE-related practices is also critical. This set of information is provided to propose the CE implementation framework for building projects in Taiwan.

As mentioned in the literature review section (see Section 2.1), Chang and Hsieh [10] have also conducted a case study of a CE-focused pilot project in Taiwan on industry level. One of their key findings is that even though the Taiwanese government has high awareness of CE implementation, the rest of the parties in the industry are still falling behind, especially the manufacturers, who should be the core players in the industry for CE. This finding is consistent with the discussion in the previous section (see Section 5.1), showing that many manufacturers-centered CE practices such as product as a service, prefabricated system, and modular and flexible unit are still uncommon. In their findings, the lack of incentive given by governments is the key challenge, while the establishment of

financial incentives and platforms for building material exchange are the key enablers for CE in building industry in Taiwan.

5.3. Suggestion on Implement Circular Economy in Building Projects in Taiwan

As mentioned by the interviewees and discussed in the previous section (see Section 5.1), identifying the suitable project items for CE-related practices is important for CE implementation in Taiwanese building projects. Therefore, the key CE-related practices summarized in previous case study are further categorized not only by five types of building life-cycle and 5R framework but also by six common engineering categories of building project in Taiwan, which are foundation and structure, exterior, interior, mechanical, electrical, and plumbing (MEP), furniture and appliance (F & A), and other, and the CE-related practices that are noted as not to be implemented in the short term by interviewees are excluded in this discussion. An implementation framework is proposed based on this discussion and shown as Table 9. When project stakeholders are considering which CE-related practices to implement, they can review the relevant project items, phases, and 5R principles for implementation based on this proposed framework.

Table 9. Suggestion on CE-related practices, their related 5R principles, project items, and phases to implement in building projects in Taiwan.

Category	Item	CE Related Practice	5R Principles					Lifecycle
			Rethink	**Reduce**	**Reuse**	**Repair**	**Recycle**	
Foundation & Structure	System	Lightweight structure		•				P & DP
		Prefabricated system (prefabricated staircase)		•				CP
	Steel [1]	Electric arc furnace steel (recycled/upgraded steel)					•	CP
		Standard length steel bars		•				CP
		Flexible frame				•		P & DP
	Concrete [1]	Recycled concrete aggregates, fly ash cement					•	CP
Exterior	Components	Standardization of sizes		•				P & DP
		Prefabricated panel/facade		•				P & DP
	Materials	Reusing green materials			•			CP
		Using recycled materials					•	CP
Interior	Components	Standardization of sizes/		•				P & DP
		Modularization of space			•			P & DP
		Prefabricated panel/partition		•				P & DP
	Materials	Reusing green materials			•			CP
		Using recycled materials					•	CP

Table 9. *Cont.*

Category	Item	CE Related Practice	5R Principles					Lifecycle
			Rethink	Reduce	Reuse	Repair	Recycle	
MEP	HVAC	Product as a service	●	●	●	●		WLC
		Smart energy saving system		●		●		P & DP
	Lighting	Product as a service	●	●	●	●		WLC
		Smart energy saving system		●		●		P & DP
	Mobility	Product as a service	●	●	●	●		WLC
		Smart energy saving system		●		●		P & DP
	Electrical	Solar energy system/heat recovery system		●				P & DP
		Smart energy management		●		●		OP
	Plumbing	Water recycle system		●				P & DP
		Smart water management		●		●		OP
F & A	Furniture	Product as a service	●	●	●	●		WLC
		Modular furniture		●				P & DP
	Appliance	Product as a service	●	●	●	●		WLC
		Modular appliance		●				P & DP
Other	Landscape [1]	Recycled pavement					●	CP
		Urban agriculture	●	●				P & DP
		Leftover recycle system					●	P & DP
	Site [1]	Modular formwork			●			CP
		Modular site office/reusable construction rack			●			CP
		Waste recycling system					●	CP
	BIM [1]	Material passport	●	●	●	●	●	WLC
		Material bank	●		●		●	DP
		Management system with QRCode	●			●		OP
		Sharing space (e.g., co-working space)	●		●			OP
		Sharing ownership (e.g., equipment, vehicle)	●		●			OP
		Exchange platform (e.g., used goods, agricultural products)	●		●			OP
		Closed loops (e.g., on-site resource circular flows)	●	●				P & DP

[1] The highlighted items are added by interviewees during interviews.

For foundation and structure engineering, three items and six CE-related practices are noted for implementation in Taiwanese building projects. Because the main structural type in Taiwan is reinforced concrete (accounting for 70% of new buildings in 2016), practices related to steel and concrete are emphasized by interviewees. For exterior and interior engineering, the main items for implementation and CE-related practices are similar, including standardization of component sizes, prefabrication of components, reusing green materials, and using recycled materials. However, one more key practice needs to be

considered for interior engineering, which is modularization of spatial units to increase flexibility of future usage. For MEP engineering, HVAC, lighting, mobility, electrical, and plumbing systems are highlighted for CE implementation. For the former three items, two CE-related practices are vital, which are product as a service and smart energy saving system. For the latter two items, resource regeneration or recovery and smart resource management system are crucial practices. For furniture and appliance, product as a service and modular design are seen as critical CE-related practices. Last but not the least, several other items are added by interviewees and should also be taken into account, which includes landscape engineering with leftover recycle system and construction waste recycling system. Modular formwork, reusable construction rack, and site office are also regarded as important items for CE implementation by interviewees, which are not underlined in Dutch pilot case study. Furthermore, building information modeling (BIM) should also play an important part in building project, for it can enable CE-related practices such as material passport, material bank and effective facility management system. To be noted, CE-related practices including sharing space, sharing ownership, and exchanging platforms should be taken into consideration in OP, and closed loop systems in P & DP.

5.4. Suggestions on Policy Implications

Further suggestions on policy implications are proposed by the authors based upon responses of interviewees on expected implementation time of key CE-related practices for building projects in Taiwan and research finding of past study [10]. In Taiwan, the relevant regulations to CE for building projects include Resource Recycling Act, Building Technical Regulations, and Government Procurement Act. Among them, the Resource Recycling Act is under Taiwan's Environmental Protection Administration, Executive Yuan, which has not been revised since 2009. Building Technical Regulations are under Construction and Planning Agency, Ministry of the Interior, which was revised in 2019 to increase the mandatory proportion of green building materials used in buildings. The Government Procurement Act is under Public Construction Commission, which was also revised in 2019 to improve the green procurement system. This shows that for building projects in Taiwan to implement CE-related practices, problems including ununified responsible government units and different paces of regulation revision will be faced. The former should be included in the overall consideration of government organization re-engineering, while the latter is related to further regulation revision. This research suggests the following considerations for latter one:

1. Article 12 of Resource Recycling Act: to add environmentally friendly design provisions for building projects, including durability, upgradeability, repairability, ease of remanufacturing and recycling.
2. Article 321 of Building Technical Regulations: to include product certification (such as Cradle to Cradle) that meets the principles of circular economy into the scope of green building material certification in Taiwan.
3. Article 26-1 of Government Procurement Act: to add supporting programs for green procurement including related enforcement rules, bidding templates, demonstration cases, and price databases that meet the principles of circular economy.

6. Conclusions

The main goal of this study is to identify the key CE-related practices for building projects and to propose an implementation framework for building projects in Taiwan. A series of case studies of CE-focused pilot projects in the Netherlands and Taiwan are conducted along with semi-structured interviews with the key project stakeholders in Taiwanese pilot projects to achieve this goal. Thirty key CE-related practices are identified via case study, along with their related 5R principles (Rethink, Reduce, Reuse, Repair, Recycle) and project phases (Planning & Design, Construction, Operation, Deconstruction, Whole Lifecycle), helping future project stakeholders to understand the concepts and features these practices for their implementation. Further, the expected implementation time (short

or long them) of these CE practices and their relevant project items (categorized by six different types) are identified via interviews. Moreover, an implementation framework of key CE-related practices for building projects in Taiwan is proposed, providing essential information of these practices including the related 5R principles, project items and phases, and expected implementation time (i.e., feasibility for implementation) for project stakeholders to consider. Also, differences between pilot cases in both countries are discussed and presented, along with reflection on research results with past study and suggestions on policy implications in Taiwan.

The main contribution of this study lies in a systematic analysis on CE-related practices by highlighting their related 5R principles and project items via case study of two countries' pilot building projects. More understanding towards CE implementation for building industry at project level is fostered. Also, different CE implementation progress of different countries can be seen via such case study. Furthermore, via semi-structured interviews with key project stakeholders in Taiwan, the expected implementation time and relevant project items of CE-related practices are identified, and an implementation framework is proposed. Similar processes can be utilized for project stakeholders whose countries are also at the initial CE implementation stage for building industry.

One of the key weaknesses of this study is the limited Taiwanese pilot cases and interviewees. In the future, after more pilot cases have appeared, more in-depth investigations and discussions on CE implementation roadmap for building projects in Taiwan can be fostered with different sectors in the industry (e.g., manufacturers, demolishers, etc.). To be noted, the CE-focused pilot projects in the Netherlands are commercial and special types (i.e., office, government, pavilion) while the ones in Taiwan are all residential types. How CE-related practices are affected by different building types should be investigated in the future.

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