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A four-quadrant conceptual framework for analyzing extended producer responsibility in offshore prefabrication construction

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Prefabrication has been widely advocated as a green production strategy to minimize the adverse environmental impacts of construction. Amid economic globalization, prefabricated construction materials are commonly sourced offsite and even offshore. As an issue emerging alongside offshore prefabrication, extended producer responsibility (EPR) is yet to be clearly identified, allocated, and implemented. This research develops a conceptual framework using a design thinking process, through which EPR associated with offshore prefabrication can be analyzed, agreed upon, and allocated. By considering the scope and scale of the responsibility and the procurement methods, the framework comprises four quadrants representing four typical scenarios for implementation of the EPR principle. It is applicable for both short-term and lifelong EPR analysis, in both traditional and integrated project delivery contexts. The framework will be particularly useful for devising public policies to achieve an onshore and offshore stakeholder win-win situation.

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1. Introduction

Prefabrication construction has been widely advocated around the world as a “clean” production strategy leading to fewer job-site environmental impacts because of reductions in material waste, air and water pollution, dust and noise, and overall energy costs (Lu and Yuan, 2013; Jaillon and Poon, 2014; Tam et al., 2015). In contrast with cast in-situ construction, prefabrication involves pre-assembling structural components in factories or other manufacturing sites and transporting complete or sub-assemblies to the site where the structure is to be constructed (Tatum et al., 1986). This may also be preferred to as “offsite construction”, where structures or components of structures are built at a location different from that of their use (Gibb, 1999). Prefabrication construction, by shifting a portion or even whole of in-situ fabrication works to offsite factories and into production lines, extends “construction project management” to include the manufacturing-era notion of “production management”. Although prefabrication has been argued to help minimize construction and demolition (C&D) waste, the construction and operation processes of buildings were responsible for 39% of energy-related carbon dioxide (CO2) emissions in 2017 (Global Alliance for Buildings and Construction, 2018), while in most developed countries construction contributes 20–30% of solid waste ending up in landfills (Bao et al., 2020; Chi et al., 2020). It remains a concern - how to allocate environmental responsibilities in the face of C&D waste management pressure.

Further to prefabrication construction, increasingly we are seeing “offshore prefabrication” with the internationalization of construction amid economic globalization; a term used by Lu and Yuan (2013) to refer to the growing phenomenon of construction clients sourcing prefabricated components from other regions/countries. For example, a big German construction company Hochtief has been developing a worldwide logistics operation in China to procure resources and has developed a joint venture with a material testing company there (Reina and Tulacz, 2007). Hong Kong’s massive prefabrication construction industry has moved offshore to the Pearl River Delta in Mainland China to benefit from its cheaper labor and materials, and greater space (Lu and Yuan, 2013). A similar shift is observed in Singapore, Japan, and other regions in which construction is in high demand and there is heavy
work using a design thinking process. Through this framework, EPR thus lead to the research question: how to implement EPR in diverse environmental regulations or policies? These dilemmas in prefabrication is faced with multiple administrative authorities with offshore prefabrication? How to deal with the situation that offshore producers so that a predatory economy does not arise around offshore prefabrication? How to deal with the situation that offshore prefabrication can be analyzed and allocated, fostering a win-win situation among stakeholders including clients, designers, contractors, manufacturers, and environmental management authorities. The remainder of the paper is structured as follows. Subsequent to this introductory section is an EPR and offshore prefabrication discourse to international construction and international business, and issues associated with both. What is unique in offshore prefabrication in addition to the concerns of prefabrication construction is that waste stays in the offshore regions where the components were fabricated. Should clients in the onshore place importing prefabricated components adopt an “out of sight, out of mind” approach?

The concerns on the allocation of environmental responsibility in offshore prefabrication fall into the domain of extended producer responsibility (EPR), which is first defined by Lindhqvist (2000) as an environmental protection strategy aimed at ensuring the manufacturer of a product is responsible for its entire life cycle, including takeback, recycling, and final disposal. EPR is an environmental policy approach of Organization for Economic Co-operation and Development (OECD, 2001), which extends producers’ physical and financial responsibilities to the post-consumer stage of a product’s life cycle. Advocates of EPR are particularly focused on channelling back to producer’s responsibilities for dealing with waste, forcing a shift from the traditional silo of production to a more holistic approach encompassing not only design, production, marketing, and distribution of products, but also eventual recycling. Already explored as a legislation or law in developed economies including Europe (European Parliament and the Council of the European Union, 2008), the US (Nash and Bosso, 2013), Canada (Canadian Council of Ministers of the Environment, 2017), and Japan (Ogushi and Kandlikar, 2007), EPR is now being introduced with its implications in the fields of packaging waste (Nahman, 2010; Pires et al., 2015), management of waste electrical and electronic equipment (Manomaivibool, 2009), vehicle remanufacturing (Xiang and Ming, 2011), plastic products (Leal Filho et al., 2019), and buildings (Acree Guggemos and Horvath, 2003).

However, the implication of EPR in offshore prefabrication is complicated compared to other manufacturing fields. Precast construction components normally have a service life of fifty years or longer before the building is demolished. How, in reality, can EPR operate with regards to, e.g. takeback and demolition waste recycling? If an extra fee is imposed during importation, for example, manufacturers may simply add it to the selling price. Offshore prefabrication clients are not always in a buyer’s market. Should they also extend responsibilities for occupational health and safety, working environment provision, professional standard upholding, corporate social responsibility, and local talent training to producers so that a predatory economy does not arise around offshore prefabrication? How to deal with the situation that offshore prefabrication is faced with multiple administrative authorities with diverse environmental regulations or policies? These dilemmas thus lead to the research question: how to implement EPR in offshore prefabrication construction with regards to multiple stakeholders and procurement methods?

This research aims to develop a conceptual analytical framework using a design thinking process. Through this framework, EPR associated with offshore prefabrication can be analyzed and allocated, fostering a win-win situation among stakeholders including clients, designers, contractors, manufacturers, and environmental management authorities. The remainder of the paper is structured as follows. Subsequent to this introductory section is an EPR and offshore prefabrication literature review in Sections 2 and 3, respectively. Section 4 is a description of our design thinking research methodology. Section 5 presents our conceptual framework, elaborating on its components and how it can be used. Section 6 is an in-depth discussion of the EPR framework, including its pros and cons, prospects and challenges, followed by a conclusion in Section 7.

2. Extended producer responsibility

Extended producer responsibility (EPR) is an environmental policy approach to examining responsibilities for the environmental impacts of products throughout their lifecycle, first introduced in a 1990 report to the Swedish Ministry of the Environment. As an environmental protection strategy, EPR makes the manufacturer of a product responsible for its entire lifecycle including takeback, recycling, and final disposal. The OECD later reviewed legal and administrative approaches to EPR, analysing their economic efficiency and environmental effectiveness to define EPR as a producer’s full or partial operational and/or financial responsibility extended to the post-consumer stage of a product’s life cycle (OECD, 2001). EPR was first implemented in developed countries. For example, the European Parliament passed a directive requiring its member countries to establish an EPR program for plastic products (Leal Filho et al., 2019). Twenty-three states in the US have adopted EPR-based legislation for end-of-use treatment of products (Ozdemir et al., 2012), while Japan has enacted an EPR law covering TV sets, refrigerators, air conditioners, and washing machines (Jang, 2010). More recently, EPR has begun to be introduced in developing countries, such as India (Chandra, 2020), Brazil (de Miranda Ribeiro and Krug, 2020), Ethiopia (Kiria and Woldemikael, 2020), and China (Gu et al., 2017; Hong et al., 2020).

EPR programmes have been explored in many contexts. Basically, all the EPR programmes can be divided into two groups, either design improvements of products and product system, or downstream improvements with a guarantee of high levels of collection, treatment, and reuse or recycling in an environmentally sound and socially responsible manner (Manomaivibool, 2009). Particularly, a widely publicised example is Germany’s Green Dot System, which makes manufacturers and distributors of packaging responsible for establishing and managing a system to take back waste associated with their products. Spicer and Johnson (2004) compared three takeback approaches to the implementation of EPR, including original equipment manufacturer takeback, pooled takeback, and third-party takeback. Atasu and Subramanian (2012) distinguished two levels of EPR: individual producer responsibility, and at sector or industry level, collective producer responsibility requiring some form of producer responsibility organization (PRO) to be established. The rules for PRO participation vary for different EPR programmes (Mayers, 2007). Some establish a single PRO while others establish multiple PROs, with each competing for business from the market. While a universally applicable EPR programme does not exist (Manomaivibool, 2009), such programmes have been widely acknowledged as a strategic waste management solution.

An attraction of EPR is the incentive it creates for producers to consider post-consumer waste management costs when making decisions about product design (Pazoki and Zaccour, 2019). It can help promote environmental goals, such as waste prevention and reduction, increased use of recycled materials in production, and increased resource efficiency (OECD, 2001, 2005). Given problems that have led to the adoption of EPR, including lack of landfill space, contamination, hazardous waste production, and abandonment of products in the environment (Spicer and Johnson, 2004), an EPR programme should be designed by considering industries and products covered by the policy context, the forms of organization, and the economic, social and cultural context in which the programme operates (OECD, 2005). Generally, there are two ways to achieve EPR programmes by a legal means, economic regulations and administrative controls. Economic regulations aim to stimulate stakeholders to adopt EPR by a series of economic mechanisms, such as ‘deposit-refund’ mechanism and lease or service economy mechanisms, while administrative control measures are mainly to improve the market access threshold for the industry, government
supervision and recognition (Xiang and Ming, 2011). Despite the fact that EPR can provide substantial benefits, its implementation still has a large room for improvement, at present, most EPR legislations are organized at sectoral level due to the convenience for implementation, where costs for the collection and recycling are shared among participants based on the market of products in the market, but this approach damages the ambition of individual companies to develop more circular products (Milios, 2018).

Some pioneers have explored the adoption of EPR in the construction industry due to the large amount of waste generated (Lu and Tam, 2013). Guggemos and Horvath (2003) explored EPR strategies for buildings, finding that, due to the uniqueness of building products, takeover policies of other industries are infeasible for entire buildings but possible for some building materials and components. Similarly, Balba et al. (2013) evaluated EPR potential for different construction materials in metro Vancouver and found that EPR can only be recommended to several types of materials. Generally, compared with the exploration of EPR in other industries, to probe into EPR in the construction industry is still in its infancy. Particularly, how to analyze and allocate EPR in cast in situ and offshore prefabrication construction remains unsolved.

3. Offshore prefabrication construction

EPR in construction cannot be understood without appreciating the heterogeneity of the industry. Construction products such as buildings and bridges are bespoke, unlike the standardized, transferable products that are designed, prototyped, and massively produced for the market. There is a long production cycle for construction outputs, from concept to project completion and then outputs normally having a lifespan of over fifty years. C&D waste is mainly generated at the construction and demolition stages at opposing ends of a building’s lifecycle. Unlike standardized products which are produced by major firms, design or construction services are provided by a myriad of fragmented companies contracted to do a parcel of jobs, leading to the widespread discontinuity problems. Production services in the construction industry are often organized under different projects. It is extremely difficult, if not impossible, to allocate any takeback responsibility to these temporary organizations which will dissolve after project completion. All of these factors contribute to the conundrum of EPR in construction.

In considering EPR, prefabrication is closer to the known production. This manufacturing process generally takes place at a specialized factory or manufacturing site, where various materials are joined to form a component part of a final installation (Tatum et al., 1986). In construction, the term “prefabrication” is often used interchangeably with others, such as pre-assembly in construction (Gibb, 2001), off-site construction (Pan et al., 2008; Taylor, 2010), industrialized building (Jonsson and Rudberg, 2014), and combinations thereof, such as off-site fabrication (Gibb, 1999). Definitions of these terms depend almost entirely on the previous experience of the users, but each of them has their own focus (Gibb, 2001). For example, prefabrication emphasizes the manufacturing process of the component; pre-assembly focuses on the process of subsequent installation as a sub-unit with the location of the process not being the key point; and off-site construction highlights that some of the fabrication works have been moved from the construction site to the factory. Prefabrication construction, the term used in this paper, indicates that a certain proportion of the construction work is prefabricated (Lu et al., 2018), either as individual components, or in the assembly of building modules.

Some aspects of prefabrication construction transcend national boundaries, since economic globalization has created an interdependent market for construction companies (Ye et al., 2018). This is called offshore prefabrication construction (Lu and Yuan, 2013). The “offshore” concept is inherited from international business, where it refers to a location of business functions outside of one’s national boundaries, whether that location is land- or water-based (Roza et al., 2011). Offshoring strategy has emerged from the waves of global sourcing since the mid-1980s, when supply chains became more global and complex (Kotabe et al., 2009). The drivers for companies’ offshoring strategy are generally lower costs and abundant resources at offshore locations (Roza et al., 2011). Construction works, including prefabrication, require much material and labor, but companies are faced with rising material costs and labor shortages (Turner & Townsend, 2019). This dilemma has forced the sector to reconfigure its resources globally, and this process includes use of offshore prefabrication.

However, issues emerge with offshore prefabrication beyond those arising from the heterogeneity of traditional construction. When prefabrication takes place offshore, it is hard to ensure production standards consistency. This may lead to quality issues: the qualified components in offshore place may not be accepted due to different codes of production or cultural differences between onshore and offshore places (Gibb, 1995). Operational risks also exist for the process (Aron and Singh, 2005), meaning that processes may not operate smoothly after being offshore. Li et al. (2016) argued that fragmentation and discontinuity of the offshore prefabrication construction supply chain lead to frequent project schedule delays. Offshore prefabrication also contends with a more complex context, with added stakeholders involved such as offshore manufacturers, transporters, local authorities, and divergent regulatory environments. Lu and Yuan (2013) reflected that it is much easier to minimize waste in prefabrication than on construction sites. From a normative perspective, offshoring strategy is argued to transfer parts of responsibilities out of nations, such as responsibilities for labor or the environment (Doh, 2005; Lu et al., 2015). Amid the global resurgence of offshore prefabrication construction, revisiting EPR is warranted by incorporating considerations of diverse codes of production, multiple stakeholders, different procurement methods, and global level responsibilities.

4. Research methods

4.1. Design thinking

This study adopts design thinking, “a methodology that imbues the full spectrum of innovation activities with a human-centered design ethos” (Brown, 2008). It emphasizes “thinking like a designer” who would traditionally focus on improving the functionality of products based on client or customer needs (Brown and Wyatt, 2010). By working closely with clients and consumers, design thinking allows “high-impact solutions to bubble up from below rather than being imposed from the top” (Brown and Wyatt, 2010). There are five core characteristics of design thinking: 1) a user centered approach, 2) an integrative and holistic view on complex problems, 3) collaboration in multidisciplinary teams, 4) a mix of mental processes mainly in abduction, and 5) a strong integration of experimenting with artefacts (Geesdoerfer et al., 2016). With these characteristics, this methodology goes beyond today’s conventional problem solving, using a designer’s sensibility and methods to match people’s needs with what is technologically feasible or a viable business strategy (Brown and Wyatt, 2010).

The design thinking process consists of five steps or stages: empathize, define, ideate, prototype and test. The empathize stage is the effort to understand people within the context of challenge, with empathy providing the critical starting point for design thinking; the define stage crafts a meaningful and actionable problem statement; the ideate stage combines understandings of
the problem space and user with imagination to generate solutions; the prototype stage turns ideas into tangible products; and the test stage interacts with users again. Brown (2008) summarized these stages into three spaces, i.e. inspiration, ideation, and implementation, to indicate the process of finding problems, coming up with solutions, and implementing solutions. Design thinking is not a linear path, but a continual looping back to different places in the process (Brown and Wyatt, 2010).

With the aim of exploring a conceptual framework for EPR associated with offshore prefabrication construction, this research involves many stakeholders in onshore and offshore countries and requires multiple methods to be organized in a systematic fashion. Its nature thus lends itself to a design thinking methodology. To be well adopted, a design thinking methodology needs to be specified. For example, Geissdoerfer et al. (2016) proposed their design thinking framework based on literature synthesis, expert interviews, and multiple workshops; Cerejo and Barbosa (2012) applied their design thinking methodology with specific methods of case studies, brainstorming, and surveys. In this specific context, we specify our design thinking methodology as five design thinking process stages along with methods including interviews, brainstorming, and case studies (see Fig. 1).

4.2. Case study

The case study is a qualitative research method with concerns on how and why things occur, which allows investigations of contextual realities and differences between what was planned and what actually happened (Anderson et al., 1998). It has been widely applied for in-depth studies across disciplines as it enables researchers to gain a holistic view of a certain phenomenon, understand complex real-life activities, come up hypotheses and generate theories (Gummesson, 2000; Noor, 2008). As an important part of the design thinking methodology, a case study can adapt the conceptual framework developed from scratch into a real context, making the framework more concrete and generalizable to other settings in the world.

We conducted case studies as a specific approach of the design thinking methodology with the purpose of embedding our basic ideas on EPR of offshore prefabrication construction and its framework in an eligible context. In this way, we can test and validate our framework by linking it to the reality. We chose the Greater Bay Area (GBA) as the context of our case studies, which involves Hong Kong, Macao, and the Pearl River Delta (PRD) in Guangdong Province of China, which are located in the same area with different political systems. The Hong Kong government enacted a series of Joint Practice Notes (Buildings Department of Hong Kong, 2001, 2002) to encourage the adoption of prefabrication and modular integrated construction with the aim of supporting the Hong Kong’s massive construction programs while reducing its waste management burden. Embedding this, Hong Kong actively exploits supplies, including construction materials and precast components, produced in the world’s factory. Thousands of Hong Kong-based manufacturing businesses, including the entire prefabrication industry, have relocated to the GBA, reflected as the concept - offshore prefabrication. Lu and Yuan (2013) reported that the underlying force is to exploit the GBA’s cheap and abundant materials and labor force, similar to the foreign entities referred to above, as well as the space available. This widely explored cooperation mode and increasing environmental concerns provide an opportunity to explore EPR of offshore prefabrication construction in GBA.

We have conducted two case studies straddling over several years. The first one relates to a series of stakeholder engagement activities (e.g., meetings, visits, talks, and community engagement) initiated in 2013 by the Hong Kong government and industry to tackle Hong Kong’s urgent C&D waste management issues. Increasing waste disposal charges and exploring EPR were high on the agenda. The second case study was conducted alongside two big research projects undertaken by this team from 2014 to 2019 exploring the potential of auto-ID and BIM technologies for managing the cross-border public housing logistics and supply chain. The factory we have frequently engaged with over five years supplies around 15% of all precast components consumed in Hong Kong per annum. We have also visited most of the sizable prefabrication yards in the PRD. Although the purpose was not initially
EPR-related, these visits were an invaluable opportunity to probe into the offshore prefabrication industry between Hong Kong and the PRD and the EPR debates arising from the first case study.

4.3. Interviews

Following the design thinking methodology, a series of semi-structured interviews were conducted in the GBA, to garner insights on offshore prefabrication construction EPR. The semi-structured interview is a commonly used qualitative research method involving a series of predetermined, open-ended questions (Given, 2008). During our two case studies over the years and another recent research project concerning the GBA, we have conducted dozens of “tailing” interviews. Some were directly related to EPR, but most were about the offshore prefabrication industry in GBA. Table 1 shows the basic profiles of some particularly relevant interviewees. Some interviews were conducted face to face and others on the telephone, depending on interviewee availability, and each lasted for about 1 h. Some examples of our interview questions are:

- Prefabrication is a green technology. Roughly how much waste can it save in comparison with traditional cast in-situ?
- We know that Hong Kong’s precast components are imported from the PRD. Who should take responsibility for the waste arising from their manufacture?
- Have you heard about the EPR in the mobile phone or car industries? Do you think it is reasonable to implement it in the prefabrication construction industry? Why?
- Who do you think should be responsible for dealing with C&D waste when the prefabricated building is demolished? And how?

5. The analytical framework

We propose the conceptual framework shown in Fig. 2, aimed at facilitating stakeholders to analyze, agree on, and allocate the EPR associated with offshore prefabrication construction. The framework distinguishes the offshore place where the prefabricated products are manufactured and the onshore place where the prefabricated products are designed, assembled and utilized. Five directly related stakeholders are organized in the offshore and onshore places: prefabrication manufacturer, environmental management authority (EMA), client, designer, and contractor.

The framework can be understood from two dimensions: scope and scale of the responsibility, and procurement methods. The producers’ waste minimization responsibility can be comprehended in the short term and lifelong. By short-term responsibility, we mean saving C&D waste immediately by adopting greener prefabrication at design, prefabrication, and construction stage. This part of responsibility, like its counterparts in other ordinary products, can be identified and allocated when the building is designed, manufactured, and constructed. By lifelong responsibility, we mean the reduction, reuse, and recycling (the 3Rs) of the residual waste when the building is demolished. Such division reflects the nature of C&D waste generation, which straddles decades from construction to demolition stages of a building’s lifecycle.

The EPR of waste minimization can also be comprehended from project procurement methods. In traditional project delivery, a.k.a., design-bid-build, parties such as client, designer, and contractor are separate. They only do a parcel of the works during the design and construction stages. Contractors and subcontractors are only engaged to materialize whatever design has passed from the designer and are reimbursed when their construction services are rendered. The project team formed by these parties will normally dissolve after the project is constructed. Integrated project delivery (IPD) means methods such as design-build and public-private partnership, whereby the designer, contractor, and other parties form one consortium lasting for the duration of the design and construction period, and sometimes extending to operations and whole lifecycle. This IPD thus provides a window of opportunity to assume EPR, particularly in relation to the 3Rs of residual waste.

By following the two dimensions, the conceptual framework is developed as a four-quadrant system, each containing a typical EPR scenario, as shown in Fig. 2. Each of the scenarios is elaborated upon in the following subsections.

5.1. Scenario I: Short-term responsibility in traditional project delivery

In traditional project delivery (TPD) methods, the environmental management agency (EMA), client, designer, contractor onshore, and manufacturer offshore are the key stakeholders. The EMA imposes C&D waste minimization responsibility on the client, who will normally pass this responsibility on to the designer and contractor. They enter separate contracts with the client and have no contractual relationship with each other. The contractor will also have a contractual relationship with the offshore manufacturer. Under this situation, responsibility shirking between designer, contractor, and manufacturer occurs frequently (Lin et al., 2017), which adds management difficulties to clients and hampers the achievement of waste minimization goals.

Short-term responsibility, i.e., immediate waste minimization, can be achieved through greener design, materials, and prefabrication technology. The client will require cleaner prefabrication products designed and delivered by the parties as mentioned above. Under EPR, clients and designers will also transfer responsibilities to manufacturers. Ideally, offshore manufacturers will minimize waste generation by adopting greener design, materials, or technologies. Meanwhile, the contractor and manufacturer can argue that they just receive the design and produce it. There is not much they can do to assume this EPR and achieve the designated sustainability goals. That is, in TPD methods, even under the pressure of EPR, it is still highly possible that the contractor, manufacturer, and designer tend to shirk from short-term waste

| No. | Role                                | Years of experience | Location                    |
|-----|-------------------------------------|---------------------|-----------------------------|
| A   | Prefabrication manufacturer         | >20 years           | Shenzhen and Hong Kong      |
| B   | Project Manager of a metro construction project | >5 years           | Shenzhen                   |
| C   | Manager of Hong Kong’s public housing program | >20 years           | Hong Kong                  |
| D   | Director, Hong Kong Green Building Council | >15 years           | Hong Kong                  |
| E   | Professor/expert of recycling waste materials | >30 years           | Hong Kong                  |
| F   | Chairman, Association of Construction Materials | >20 years           | Hong Kong                  |
| G   | President, Association of Recycle Industry | >20 years           | Hong Kong                  |
minimization responsibilities and pass the duties to others. Therefore, the EMA and client need to formulate stricter waste minimization regulations and stronger supervision forces, nevertheless it is hard to ensure their effects. The EPR effectiveness under this scenario is thus discounted.

5.2. Scenario II: Short-term responsibility in integrated project delivery

In integrated project delivery (IPD), the key stakeholders remain the same, but their relationships are different. The client contracts with a consortium of design and construction firms. This consortium will have a contractual relationship with the offshore manufacturer and sometimes even internalize a producer within their remit of business. Unlike in TPD, the consortium will provide the client with one-stop services including design-build, or even operation/facilities management. It is the only responsible subject for the project. The client only focuses on specifying the services it needs, the goals to achieve, and the responsibility description for the consortium.

Short-term responsibility imposed by the EMA on the client can be written as a part of the specification and legitimately passed to the design and build consortium. With the more integrated services it supposedly provides, the consortium can work closely with the offshore manufacturers to assume EPR, e.g., by pondering greener design, and adopting more sustainable and recyclable materials, a cleaner offshore production strategy, and a cleaner onshore assembly method. The consortium can achieve the short-term waste saving goal by collaborating with the offshore manufacturer. The accountability of the waste minimization is easier to conduct for both the client and the EMA. EPR under this scenario can therefore stimulate a virtuous circle among stakeholders by facilitating greener design and cleaner production approaches to reduce wastes in the short-term and enhancing the efficiency of waste minimization at a lower regulation cost.

5.3. Scenario III: Lifelong responsibility in traditional project delivery

Lifelong responsibility is concerned with the 3Rs of residual waste when a building comes to the end of its service life. For ordinary products such as glass bottles, cars, or airplanes, their EPR can be assumed when they are produced, or at least, traced back to the makers. However, for building products, which utilize materials from various suppliers and normally last fifty years or longer, EPR is difficult to identify and allocate. This is particularly true for TPD, as stakeholders such as clients, designers, contractors, and manufacturers are fragmented and unlikely be traceable after fifty years.

In this scenario, the stakeholders and their relationships remain almost the same as those in Scenario I. What is new is the introduction of a producer responsibility organization (PRO): a non-profit organization jointly supported by offshore manufacturers and onshore EMA to be responsible for the onshore 3Rs of all manufacturers’ prefabricated products when the buildings are

Fig. 2. An EPR analytical framework in offshore prefabrication construction.
demolished. When the building is constructed, the PRO will sign a contract with the client, the contractor, or the manufacturer, who will pay a service fee based on the industry's standard. Even if the stakeholders are non-traceable when the building is demolished, the PRO is still there to handle the 3Rs on behalf of the manufacturers or other stakeholders who entered the contract. In fact, this practice is widely seen in analyzing, agreeing upon, and allocating the EPR of ordinary products. Upon demolition, the recyclable and reusable materials can be treated and exported back to the manufacturers. The manufacturers can also receive subsidies from the PRO to maintain a healthy balance sheet. Therefore, manufacturers will be driven by the profit of low-price recyclable and reusable materials and subsidies of reduced waste to employ greener materials during production. By paying a fee now for a product to be taken back in fifty years, waste minimization responsibility is placed upfront. Stakeholders, in particular manufacturers, will be incentivized to carefully consider strategies to minimize the C&D waste generation. With the PRO to take the lifelong responsibility, the whole industry is better organized and incentivized for the greener, cleaner and more sustainable development. However, while the designer is not contractually connected with the contractor and manufacturer, the latter may find it difficult to change the design which is not green and sustainable enough. The PRO can neither communicate design requirements directly to designers. Consequently, the PRO, contractor, and manufacturer may shirk the EPR to designers. Thus, the impact of the EPR under this scenario can also be discounted.

5.4. Scenario IV: Lifelong responsibility in integrated project delivery

This scenario concerns the EPR in a building project adopting IPD. We maintain the design of the PRO, which will assume lifelong 3R responsibility as in Scenario III. The PRO will have a direct relationship with the EMA, client, contractor, and the manufacturer. What is slightly different here is the contractual relationship with the design-construction consortium. The manufacturer can have a direct strong relationship with the design team of the consortium, and it makes the communication of greener design easier and more efficient. The PRO can also directly talk to the designers to improve green design requirements and standards. This approach will get the designers more involved in the whole ecosystem and consider waste minimization since the start of design. The communication cost between the stakeholders will thereby be reduced. Moreover, by working with the offshore prefabrication manufacturer, the design-construction consortium can directly undertake EPR. Unlike the temporary project teams in TPD projects, the consortium in this IPD is a long-standing organization in a good position to undertake EPR for cleaner production and waste reduction. Lifelong EPR in IPD methods will turn the industry more compact and efficient in reducing waste by shifting design closer to manufacturing and construction at an earlier stage. The impacts of EPR can reach its full potential under this scenario.

6. Discussion

Despite the promise of EPR in minimizing C&D waste, all the unique characteristics of construction products, productions, and practices make EPR implementation difficult. Our research approaches the problem by structuring it into two dimensions; short- and long-term responsibility, and traditional project delivery (TPD) and integrated project delivery (IPD) methods. The division into short- and long-term responsibility recognizes that waste is mainly generated during construction and demolition, which may be decades apart. The division between TPD and IPD recognizes the fragmentation and discontinuity issues in construction. The two dimensions divide the problem domain into a four-quadrant system, wherein each quadrant represents a typical industrial scenario for analyzing EPR.

One finding, not explored before, is that IPD as a procurement innovation (Lu et al., 2013) has great potential for assuming EPR. Interviewee A, a prefabrication manufacturer, said:

In our (construction) business, what are we afraid of? It is long tail. Like it or not, it is our nature to get it done, get yourself paid, and quickly move on.

This view was echoed by Interviewee F, who runs a materials supply business. Nevertheless, a clear trend in recent construction management literature is to advocate IPDs such as design-build (DB), public-private partnership (PPP), and build-operate-transfer (BOT). Whilst prevailing literature is concerned with integrated services (Gu et al., 2019), innovative financing (Mayers, 2007), or lifelong and stable services (McKerlie et al., 2006), this research finds that IPD, by reducing discontinuity and organizing compact consortiums, increases the accountability and efficiency of implementing EPR. It also supplements the existing theory of project management that IPD can facilitate coordination and better performance (Mesa et al., 2016; Hamzeh et al., 2019) for waste management.

It is apparent that, to sustain their existence, the operation of producer responsibility organizations (PROs) should be superior to existing C&D waste management services. Many companies specializing in the C&D waste management are thriving in emerging cities such as Shenzhen and Suzhou (Bao et al., 2019; Bao and Lu, 2020; Li et al., 2020). As competitive market entities, they can be commissioned as the PRO. This was endorsed by Interviewee B:

These companies are doing good business in Shenzhen’s zero waste strategy. They are specialized in construction waste management, with their onsite and offsite plants. They can stand for long if we further pursue a zero-waste society with the economic development in this city.

As business lines from both the regular market and the EPR, these companies will be in a more stable position to assume the EPR. This exploring practice is worth promoting in other countries and areas to found PROs based on existing waste management companies. The PRO can originate from either a single company or a consortium of several companies. This approach can both benefit the contractors and clients by shifting their waste management responsibility to specialized organizations and profit the waste management companies by expanding their service scale and influences in the construction ecosystem. By doing so, the stream of the construction industrial chain will be completely integrated (Briscoe and Dainty, 2005).

Implementing EPR can also exploit technological advancements. In our previous studies, Internet of Things (IoT) technologies, such as global positioning system (GPS), radio frequency identification (RFID), Quick Response (QR) code, and smart construction objects (SCOs), have been adopted to track the transportation of precast components (e.g., façades, tile beams, volumetric kitchens) from the GBA to Hong Kong and in real time displace their status information in a building information model (Niu et al., 2016; Chen et al., 2017). Similarly, these embedded technologies can be used to track and trace C&D waste (Lu et al., 2017). What is under explored is the emerging blockchain technology, which keeps immutable, cryptographic, and verifiable information in a decentralized ledger that transacting parties cannot change or deny (Li et al., 2019). This technology seems to present a unique opportunity to handle discontinuity issues for prevailing project delivery organizations in assuming EPR. Information on waste generation and its agreed upon and allocated EPR can be safeguarded in blockchain, and
cannot be shirked by responsible parties even decades later. All these techniques enhance the traceability and accountability of information to guarantee the successful implementation of EPR.

The EPR framework will not survive without several factors being carefully considered. First, we need to change the mindset that producers/manufacturers can do little waste minimization as they receive a design from upstream. Interviewee A is a typical holder of this mindset:

No problem. If you pay, I can do whatever you ask me to do.

The separation of design and production in construction is an issue but increasingly the practice is to involve downstream manufacturers in product design through IPD or similar methods. This changing practice will provide an opportunity to refine the design to achieve EPR goals (OECD, 2001, 2005). However, from a case study, Huang et al. (2019) found that EPR implementation leads to lower recyclability and higher durability in the photovoltaic panel industry. Therefore, design should not be separately considered in the EPR framework but should be integrated with other processes. Second, EPR needs a business case. For the short-term responsibility (i.e., immediate construction waste saving), the key is to have a mechanism to share the saving so as to incentivize different parties to sustain their EPR efforts. To quantify the saving, a baseline of the prevailing waste generation in current construction practice should be drawn, e.g., using various waste quantification methods (Xu et al., 2020). For the long-term responsibility, manufacturers will be incentivized by the subsidies and low-price recyclable and reusable materials. In the business case, risk allocation and profit-sharing between stakeholders (Jones et al., 2018) should be carefully designed to motivate the virtuous circle.

Implementation of the EPR framework may be challenged by the changing relationships of a buyer’s or a seller’s market. In our case study, Interviewee A runs a massive offshore business, supplying around 15% of all prefabrication components used in Hong Kong. He serves various clients. It is typical for him to use a hedging and coordination model (Zhai et al., 2019) to accommodate multiple clients in multiple periods. When he was in a seller’s market, imposing an EPR on him may not have had the expected outcome. Interviewee C said:

Boss A tends to bid a lot of jobs, some are public clients like us, some are private real estate developers. You have to talk to them nicely. Talking about EPR? Don’t joke.

He may simply place the EPR fee in his bids, meaning it is actually paid by the client. Even worse, he may not bid the project altogether because of the EPR. Looking at industry level, prefabrication manufacturers in the region not only serve Hong Kong, Japan, and the US, but also face strong demand from the domestic market. Interviewee D reflected that:

Nowadays, it is more and more difficult to negotiate with the local governments in the PRD. Recently, you see, Guangdong tightened the import of twenty-four types of waste materials.

To impose an EPR on these manufacturers may not have the desired result. Transaction cost theory will help explain this dilemma. If such transaction cost is only imposed on seller in one region, they would rather give up the transaction because they don’t need to pay the EPR fee in other regions of the global market. But if this EPR fee is embedded in a global system, even a partially global system, the transaction cost will not be possibly escaped and EPR will result in a more structured industrial chain with a reduction in transaction costs and achieves greater consistency (Hickle, 2016).

Implementation of the EPR framework is also highly contingent on the changing ideology of globalization. While it has progressed quickly despite challenges (e.g., climate change, economic inequality, predatory economy), it has never been challenged like now. Heated debate on globalization has been triggered by trade wars and populism spreading around the world. The global Coronavirus disease 2019 (COVID-19) outbreak is further fueling the globalization backlash (Goodman, 2020). The world will definitely revisit current logistics and supply chain (LSC) paradigm, and offshore prefabrication as a means of configuring construction LSC globally and its EPR implementation, will not be immune. Contingency theories should be employed in the analysis of long-term EPR implementation and LSC paradigm revisiting (Khalid et al., 2015).

7. Conclusion

Construction materializes the built environment, but it also generates a huge amount of waste. Over the years, it has become common industry practice to import raw materials and prefabricated products from offshore regions. In the context of the offshore prefabrication construction, this research considers how to implement the EPR principle, which aims to extend producer responsibilities for reducing, reusing, and recycling C&D waste so as to encourage them to pursue production in a cleaner way, e.g., by adopting green design, using recyclable materials, and developing low waste technologies. We develop a conceptual framework to analyze, agree upon, and allocate EPR in offshore prefabrication construction, recognizing two dimensions of difficulties: (a) responsibility for reducing, reusing, and recycling arising at the stages of construction and demolition, decades apart; and (b)fragmentation and discontinuity of stakeholders making the EPR untraceable and difficult to assign.

By following the two dimensions, we develop our framework into a four-quadrant system, each containing a typical EPR scenario. Scenario I is concerned with how to analyze, agree upon, and allocate short-term responsibility (i.e., immediate saving of construction waste) when a traditional project delivery (TPD) method (e.g., design, bid, and build) is adopted. Producers (e.g., contractors and offshore manufacturers) often adopt a passive stance, producing whatever design the client/designer presents. Scenario II concerns the long-term responsibility when an integrated project delivery (IPD) method (e.g., design-build, public-private partnership) is adopted. An IPD consortium as a single entity will be in a better position than that in TPD to assume EPR. Scenario III concerns the long-term responsibility (i.e., 3Rs of residual waste when a building is demolished) when a TPD method is adopted. In this scenario, a producer responsibility organization (PRO), widely seen in electronic and car industries, is introduced to overcome fragmentation and discontinuity problems. Scenario IV relates analyzing, agreeing upon, and allocating long-term responsibility when an IPD is adopted. In this scenario, both the PRO and IPD consortium can act as a long-standing organization to assume EPR.

EPR is an innovative principle aimed at alleviating the downside of the prefabrication construction/production. Moreover, several managerial implications are discussed: (1) Implementation of the EPR conceptual framework should exploit procurement innovation and advanced technological instruments, e.g., auto-ID and blockchain; (2) It should consider changing the ingrained passive mindset and seeking a business case to sustain in the market; (3) Special attentions should be paid to the shifting relationships of a buyer’s or a seller’s market commonly witnessed in the offshore prefabrication construction; (4) EPR in construction, emerging from a conspicuous background of economic globalization, now faces changes in this background, triggered by climate crisis, trade wars, populism, and more recently the outbreak of COVID-19.

This research extends the implication of EPR to C&D waste management in the construction industry which is different from other traditional industries due to its long production cycle and heterogenous characteristics. It contributes to the project management theory by supplementing that IPD is not only a better
project delivery method for communication and project performance but also for waste minimization and sustainable project. It further contributes to the stakeholder management theory by pointing out that fragmented stakeholders are difficult to manage while a consortium of stakeholders will largely solve the problem. For the waste management practice, it extends the waste minimization responsibility to producers, suggesting an ideal approach to implement EPR in offshore prefabrication construction by introducing a novel PRO and the IPD methods, and finally aims to reduce C&D waste from the upper part of industrial chain.

**CRediT authorship contribution statement**

**Jinying Xu:** Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Meng Ye:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Weisheng Lu:** Conceptualization, Formal analysis, Funding acquisition, Supervision, Writing - original draft, Writing - review & editing. **Zhikang Bao:** Data curation, Writing - original draft. **Chris Webster:** Writing - review & editing.

**Declaration of competing interest**

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

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