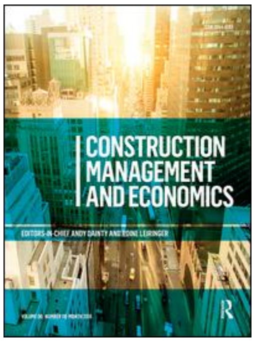

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Capital project planning for a circular economy

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ABSTRACT
Achieving true sustainability in the conceptualization of new building projects requires radical change compared to traditional green-field projects; circular building principles in a circular economy must become a fundamental part of the process. These principles include product recovery management, life cycle assessment (LCA), design for disassembly sequence planning, adaptability, deconstruction, closed materials loops and dematerialization. These principles recognize the importance of the End-of-Life stage in existing buildings, including adaptive reuse as an attractive alternative in a circular economy. However, the early phases of capital project delivery lack well-developed methods to: (1) decide amongst green-field construction versus adaptive reuse, (2) pre-project planning for closed-loop cycle construction and (3) plan for the optimization of the benefits of adaptive reuse. In this article, we argue that the early capital projects delivery phases for a circular economy should have distinct stages, decision gates and more appropriate planning methods, such as selective disassembly, LCA monetization protocols and optimization methods. An investigation of related studies underpins the capital project planning framework proposed and the research that must still be accomplished to enable a more circular economy in the capital projects sector.

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Adaptive reuse; capital projects; sustainability; circular economy; closed-loop cycle construction; net environmental impacts; life cycle assessment

1. Introduction

Sustainability in construction has shifted from an original focus on cleaner and leaner delivery of conventional projects to a restorative and regenerative approach. Sustainable construction had been mainly focused on the development of new high-performance green buildings and retrofitting, rather than research in life cycle performance in terms of sustainability (Ofori 1998, Kibert 2007, Plessis 2007, Pomponi and Moncaster 2017). This change is grounded in the recognition that an enormous proportion of all the materials ever extracted are in today's built environment, that the current economic model is reaching its limits and that a new circular model should be our path to true sustainability (Hill and Bowen 1997, Ofori 1998, Costantino 2006, Kibert 2007, Lacy and Rutqvist 2015). Therefore, circular building principles and green design methods need to become a more central part of the capital building project process (Shiers *et al*. 2006, Kibert 2007, Sassi 2008, Volk *et al*. 2014, Smith and Hung 2015). They have the purpose of reducing environmental impacts and increasing economic benefits from a total life cycle perspective (Smith and Hung 2015).

While circular paradigms of project cost, quality and schedule have always played a part in capital projects delivery, essential to the definition of a project is that it has a beginning and an end. This presents a dilemma. How do we manage a project delivery process that has phases in a cycle, rather than an obvious beginning or end? When a new need for infrastructure or space arises, how do we develop a solution? And, what role does early planning play? Noteworthy are several studies that have recognized the importance of the End-of-Life (EoL) stage in buildings, and the opportunity of their adaptive reuse as a superior alternative to new buildings in terms of sustainability (DHUD 2001, Teo and Loosemore 2001, Cantell 2005, Douglas 2006, Huovila 2007, Bullen 2007, Schultmann and Sunke 2007, Langston 2008, Langston *et al*. 2008, Wilkinson *et al*. 2009, Highfield and Gorse 2009, Wilson 2010, Tan *et al*. 2014, Conejos *et al*. 2015).

It is also widely known that an appropriate "pre-project" planning or "front-end" project management leads to improved project performance in terms of cost, schedule and operational characteristics (CII 1994, Dumont and Gibson 1996, Cho 2000, Ballard 2000a, Morris 2011, Edkins *et al*. 2013). According to Edkins *et al*. (2013), despite evidence of the importance of the pre-project planning, it is still poorly understood, not well documented in the literature review, and inconsistent from project to project and between sectors. For that reason, over three decades,

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diverse industries have implemented practical solutions in the field of front-end project management showing their value to the planning process (Cho 2000). For the building industry in North America, one of the most important referents in this matter is the Project Definition Rating Index (PDRI) for buildings, which was developed by the Construction Industry Institute (CII) (Bingham and Gibson 2017). While the PDRI and the early project processes it supports (such as need identification, project definition and basis of design) have been effective for conventional capital project planning, they are insufficient in a circular economy approach.

Thus, the purpose of this article is to develop an argument that starts with the main tenets of the circular economy in the construction industry and the built environment, as defined and understood in a selection of academic literature. This creates a framework of circular building features and principles that we use to analyse the content of a pre-project planning tool for buildings. The comparison between the features associated with circular buildings and conventional ones enables us to identify dissonances or gaps between the different scenarios for the pre-project planning stage. The empirical contribution of our argument resides in the integration of the lessons learned and findings related to circular building principles and green design methods applied in an adaptive reuse case study. The theoretical contribution underlines a contextual and process-based understanding of capital project planning for a circular economy. As well, this article contributes to the theoretical foundations of pre-project planning and a stepping stone to shape future research initiatives on the topic.

2. Background

This section provides a short introduction to the main concepts addressed in this paper, the circular economy in construction, circular economy for the built environment and the implications of circular building principles in capital project delivery. In the next three sections, we expand on those ideas.

2.1. Designing for a circular economy in construction

The conceptualization of circular economy has evolved through the years and it has been gaining momentum since the late 1970s (Geissdoerfer *et al*. 2017). The shared founding principles lie in the better management of resources and waste by minimizing (or closing) material and energy loops (Lacy and Rutqvist 2015, Geissdoerfer *et al*. 2017, Pomponi and Moncaster 2017). In their work, Pomponi and Moncaster (2017) developed an exhaustive critical literature review to categorize circular economy research in the last three decades. They concluded that green supply chains and waste reduction have been the main drivers of research due to the evident opportunities, such as reductions in energy use, environmental impacts and waste production.

By definition, the strategies for engaging a circular economy in the construction industry are: long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling (World Economic Forum 2016, Geissdoerfer *et al*. 2017), and the mechanisms to afford it are: design for deconstruction, durability, adaptability, the environment, closed materials loops and dematerialization (Kibert 2007).

Therefore, construction as an industry is implementing designs and systems with improved long-term life cycle performance. The main objective is to consider closed-loop design principles. These principles can be defined as a construction involving materials and building elements from old buildings that can infinitely be recycled or reused through natural or industrial processes (Sassi 2008).

In 2008, Sassi defined criteria by which building materials can be assessed in terms of forming part of a closed loop. Jaillon and Poon (2014) demonstrated that the promotion of a closed-loop material cycle is critical to contribute to sustainability thus minimizing carbon emissions and natural resources consumption. Silvestre *et al*. (2014) proved that assessment of waste flows is an important source of data for decision-making at the EoL of building materials. Schultmann and Sunke (2007) delved into research on the energy savings that could be afforded through using different recovery techniques on deconstruction projects. All these studies support the idea that there are areas of opportunity to maximize the benefits of the resources on the EoL stage of buildings.

In a similar way, recognition of the potential of reusable building materials towards a circular economy in construction has driven diverse research in this field. A growing trend in the building industry is to reduce greenhouse gas emissions from steel production re-using steel instead (Gorgolewski 2006). In his work, Gorgolewski (2006, 2008) discusses the issues relevant to design for future reuse and the impacts on stakeholders such as the owner, designer, builder and others. Ness *et al*. (2015) proposed digital tracking of structural steel members to facilitate reuse in new buildings. Yeung *et al*. (2015) explored the geometric characterization of structural steel of *in situ* members, as a key role in the decision process for potential steel reuse. In his work, Yeung (2016) contributed to the understanding of life cycle impacts of steel reuse as an alternative to recycling. However, much of the potential for reuse depends on the state of the existing building stock as a raw material bank for new buildings (Ortlepp *et al*. 2016, Stephan and Athanassiadis 2017).

In essence, the most eco-effective sustainable strategies in a circular economy, are those that are conceptualized from the beginning to create positive impacts and beneficial footprints, rather than focusing just on doing as little damage to the environment as possible (Lyngsgaard and Guldager Jorgensen 2013, Guldager Jorgensen and Somme 2016). Adaptive reuse of buildings is often superior to new construction in terms of sustainability (Douglas 2006, Conejos *et al*. 2015). It has the potential of improving the financial, environmental and social performance of buildings, in a life cycle perspective. It takes existing buildings that are obsolete, restores them and changes their use (Bullen 2007, Langston *et al*. 2008). As part of its life cycle, a building's operational and commercial performance decreases over the years, until it falls below the expectations of its owner, or until a third party perceives a higher potential value in repurposing it. In the past, the owner options at EoL for a building and its materials would be direct reuse, repairing, refurbishing, remanufacturing, cannibalization, recycling, combustion with heat recovery, composting, incineration and landfilling (Schultmann and Sunke 2007). However, choosing any of these EoL options may be premature if the residual utility and value that could be optimized by "giving them new life" through adaptive reuse are ignored. Because of the great impact that the building industry has on the environment, failing to optimize a building's useful life can result in its residual life cycle value not being fully exploited, and with it, wasting the embedded resources. Adaptive reuse addresses this potential and optimizes the use of new and reused resources, when it is applied properly.

2.2. Analysis of the existing building stock

An accurate inventory analysis of the building stock must be a fundamental part of strategic planning for a circular economy in construction and of planning for particular capital projects. It will provide decision-makers with the necessary financial, social and environmental information to maximize project performance in terms of sustainability. Advances in Building Information Modeling (BIM), City Information Modeling (CIM) and the Internet of Things (IoT), as well as the enormous amount of data already available in virtual platforms such as Google Earth, real estate databases and public Geographical Information Systems (GIS), are enabling a realistic, dynamic and up-to-date inventory analysis of buildings stocks. It is still a challenge, however, to perform this kind of analysis, because the information is dispersed and non-unified. For example, it is difficult to know which buildings in a region are at the end of their lifespan.

Existing buildings approaching the end of their lifespan could become a "mine" of materials, since it is often more effective to recover the components through Product Recovery Management (PRM) than to produce or extract the raw materials for new ones (Schultmann and Sunke 2007, Langston *et al*. 2008). In fact, Conejos *et al*. (2014) claims that demolition and equivalent new construction of energy-efficient buildings would require decades to equal the energy savings of rehabilitating and reusing existing buildings. Hence, the largest portion of natural resources savings as well as the minimization of the environmental impacts are in retrofitting and redeveloping existing buildings rather than producing new energy-efficient buildings (IPCC 2007, Conejos *et al*. 2014), in essence "re-using" existing buildings. Thus, adaptive reuse for buildings has emerged as a broadly growing practice. However, there can be a resistance from builders and owners when they have the alternative of reusing materials. Part of this is due to the knowledge gaps about reused materials' reliability (Yeung 2016), lack of science-based user-friendly methodologies in the field (Conejos *et al*. 2014, 2015) and the underestimation of the embedded resources in the building components and materials (Teo and Loosemore 2001, Schultmann and Sunke 2007, Langston *et al*. 2008).

2.3. The importance of pre-project planning and circular building principles in capital project delivery

The capital project delivery system is a complete series of operations leading to the occupancy of a finished building. It is well known that a total project delivery system encompasses the pre-project planning, design, and construction phases of the project life cycle. It can be argued that the pre-project planning phase is the most important in a project life cycle in terms of determining the success of its outcomes (Smith 1983, CII 1994, Cho 2000, Johansen and Wilson 2006). Pre-project planning is focused on setting the major decisions of a project scope that will affect the cost and schedule performance, operating characteristics, as well as the overall financial success of the project.

For three decades, a number of research studies have investigated and demonstrated the importance of the pre-project planning phase in different industries and sectors (Cho 2000, Ballard 2000a, Johansen and Wilson 2006, Morris 2011, Edkins *et al*. 2013, Bingham and Gibson 2017). In the early 1990s, Morris (2013) proposed an alternative project management model named Management of Projects (MoP). In this model, Morris settled the framework for managing the preconstruction planning as well as downstream execution. The MoP model focuses on the project in its context, particularly on early definition of the project success factors, rather than the execution and delivery stages, as is the case in traditional project management (Morris and Edkins 2013). In 2000, Ballard termed the preconstruction planning process as "front-end" planning, and he identified this process as a fundamental part of the project definition and design phases of the Lean Construction Institute's Lean Project Delivery System. In his work, Ballard (2000b) developed and tested an approach to increase plan reliability during design processes, named the Last Planner System. Similarly, due to concerns of poor prediction of client cost and construction duration, the Egan Report (1998) Rethinking Construction proposed a specific set of performance measures of time and cost predictability. This set of performance measures is well known as the Key Performance Indicators (KPIs), and they have been studied, implemented and extended by numerous organizations. The Construction Best Practices Program (CBPP) is recognized as the leading organization involved in the production of KPIs (Beatham *et al*. 2004). In North America, for over three decades the Construction Industry Institute (CII) studied the pre-project planning phase for new buildings. In 1998, CII developed a pre-project planning tool called the Project Definition Rating Index (PDRI) for buildings, as part of a series of PDRI's for different construction industry sectors. For the purposes of this article, we consider the PDRI and its derivatives an important and representative applied tool set for this domain, as its use on hundreds of building projects has been well documented by the CII.

Despite its efficacy, a linear project life-cycle paradigm still dominates the pre-project planning for capital project delivery. Linear project life cycle stages include extraction, construction, operation and EoL. An unlimited amount of natural resources is assumed, and their restoration or preservation, as a part of a sustainable cycle, is neglected. The evidence shows that when having strictly commercial objectives, externalities as well as environmental and social impacts, are neglected (Mokhlesian and Holmén 2012).

Under a linear project life cycle approach, even the conceptualization of a green building could result in a paradox. This approach is focused on the construction of new high-efficient eco-friendly buildings. However, according to circular building principles, a shift of thinking in the perception of sustainability in construction is necessary; switching from the traditional creative and innovative approach to a restorative and regenerative one. This change of perception is founded on the facts that: (1) an enormous proportion of all the materials ever extracted are in today's built environment (Kibert 2007) and (2) the turn-over rate of buildings is considered relatively low (Wilkinson *et al*. 2009, Beccali *et al*. 2013, Sandin *et al*. 2014, Conejos *et al*. 2014). As well, the price of materials extraction is increasing, as are the negative environmental impacts, due to the natural constraints of the more dilute and distant stocks of ores and other resources (Kibert 2007). Understanding the real value of the built environment in terms of sustainability through merging cutting-edge technology with the most updated and realistic buildings' databases (Langston 2013, Ortlepp *et al*. 2016, Stephan and Athanassiadis 2017) and the improvement on the monetization of environmental impacts through technological development and research in the field (Viscusi 2005, Shindell 2015, Yeung 2016) could well be improved. It is clear that while useful to date, the current implementation of pre-project planning is insufficient for capital project planning for a circular economy.

Central to this paper, is the recognition of inadequate development of capital project planning tools for achieving sustainability and circular economy objectives. As previously described, above, pre-project planning is the most important stage for construction success. Pre-project planning has been defined as, "the process of developing sufficient strategic information for owners to address risk and decide to commit resources to maximize the chance for a successful project" (CII 1994). Pre-project planning is analogous to processes in other sectors and geographic regions of the construction and capital projects delivery industry such as front-end loading (FEL), project programming, schematic design, conceptual planning, feasibility analysis and early project planning. In spite of its importance, early planning in most cases could be performed much better in the building industry. Some authors attribute this problem to the lack of studies that demonstrate quantitatively the effectiveness of the pre-project definition for buildings (Xia *et al*. 2016). Other authors claim that it is due to the lack of development of science-based user-friendly tools to assist in developing a clear project definition for buildings (Dumont *et al*. 1997, Cho and Gibson 2001).

Some of the most important tools available in this domain are the PDRI, Alignment Thermometer, Front End Planning Toolkit and Shutdown/Turnaround Alignment Review (STAR). All these tools have been developed to be functional under the traditional conditions of a linear economy approach. There is little or no evidence, however, in their fundamental development about the incorporation of a circular economy approach. We argue in the following that the early capital projects delivery phases for a circular economy should have distinct stages, decision gates and more appropriate planning methods, such as selective disassembly, LCA monetization protocols and optimization methods.

The PDRI was developed to assess projects from feasibility through the end of detailed scope and up to the project execution stage. During scope definition, the most relevant information for the project, such as general project requirements, necessary equipment and materials and construction methods or procedures, is identified and compiled to permit effective and efficient detailed design to proceed (Cho 2000). The PDRI allows project teams to assess and measure the gaps in scope definition, providing a basis to manage the process. According to Bingham and Gibson (2017), the PDRI estimates an index that measures the relative level of definition for the project, where a lower score indicates a more complete scope definition. It is completed collaboratively and often more than once in the pre-project planning phase. Over the past decades, the PDRI tools have been updated and revised, and data on their efficacy have continued to be captured (Bingham and Gibson 2017).

While the PDRI and the early project processes it supports (such as need identification, project definition and basis of design) have been effective for conventional capital project planning, they are insufficient in a circular economy approach. For example, in a linear construction life cycle approach, no constraints are recognized for material resources or their final disposal. In contrast, a circular life cycle approach aims to preserve products, components and materials at their highest possible utility and value in order to create more sustainable cycles. Tools such as the PDRI have focused principally on the market performance of building projects. Externalities such as social and environmental impacts are not included. While this perspective predominates in North America, it persists worldwide, and it has led to underestimating the real value of reusing existing building stock for an efficient circular economy. Values must change and a better understanding of capital project planning for a circular economy is needed to move forward. We pose questions and propose a framework for that purpose in the next section.

2.4. The knowledge gap – pre-project planning tools for adaptive reuse

Adaptive reuse synthesizes many of the principles and methods described in the preceding paragraphs in order to restore, reconfigure and repurpose existing buildings. An urgent need exists to develop and validate effective planning principles, methods and tools for adaptive reuse building projects. In particular, while the PDRI for buildings is known to be an effective planning tool for green-field building projects, it has limited applicability to the circular model. Complimentary tools are also required such as selective disassembly planning methods, LCA analysis procedures, and methods to justify development incentives offered by government. Thus, we propose a capital project planning framework and related research that must be accomplished to enable a more circular economy in the capital projects sector.

3. The advantages of adaptive reuse over green-field construction

Choosing adaptive reuse for a building project is a complex process. Figure 1 shows the role of adaptive reuse in the construction value chain in a circular economy, and it illustrates the capital project planning framework proposed in this article. Most of the processes identified as part of the adaptive reuse cycle in Figure 1 require further research and development. Many aspects have to be taken into account, such as the physical integrity of the building, economic issues, functionality, technological retrofits, social impact and legal and political issues. For this reason, limited research has been done regarding establishing feasible methodologies for the assessment of adaptive reuse of buildings. Some authors stress that intuition and experience are the only guides in making decisions about adaptive reuse (Highfield and Gorse 2009). We strongly disagree. Some processes and tools have been developed, such as the Adaptive Reuse Potential (ARP) model (Conejos *et al*. 2015), the adaptSTAR model (Conejos *et al*. 2014) and "smart growth codes" (DHUD 2001, Cantell 2005). However, substantially more research to enable the processes described in Figure 1 is required.

As discussed earlier, undervaluing and thus not including social and environmental impacts in existing planning tools is misleading. For example, the lower budget segment of Figure 1 summarizes part of the findings in a case study for developing an LCA-based decision-making methodology for evaluating adaptive reuse of buildings. The situation is typical. Despite the fact that the contract value of the adaptive reuse building project did not report a reduction in the final budget in comparison to green-field construction, the distribution of the construction budget was completely different. Construction materials costs were substantially lower for the adaptive reuse project than the green-field alternative. In contrast, the skilled labour expenses increased considerably. The increment of employment represents a completely unrecognized social benefit, and the reduction of the demand for raw materials promotes an intelligent economy instead of a resource-based one.

Most sustainable development arguments seem to miss this point and thus lose effectiveness in motivating local change. While the impact of the sheer size of the existing built environment from an energy efficiency and retrofitting perspective has not been neglected, appreciation of the potential for adaptive reuse as opposed to recycling and reconstruction has been missing. That said, adaptive reuse can be expensive. It has a high impact on the EoL value for a building. If a building is technically difficult to recover, it might actually increase its environmental and economic cost in comparison to a new building. Therefore,

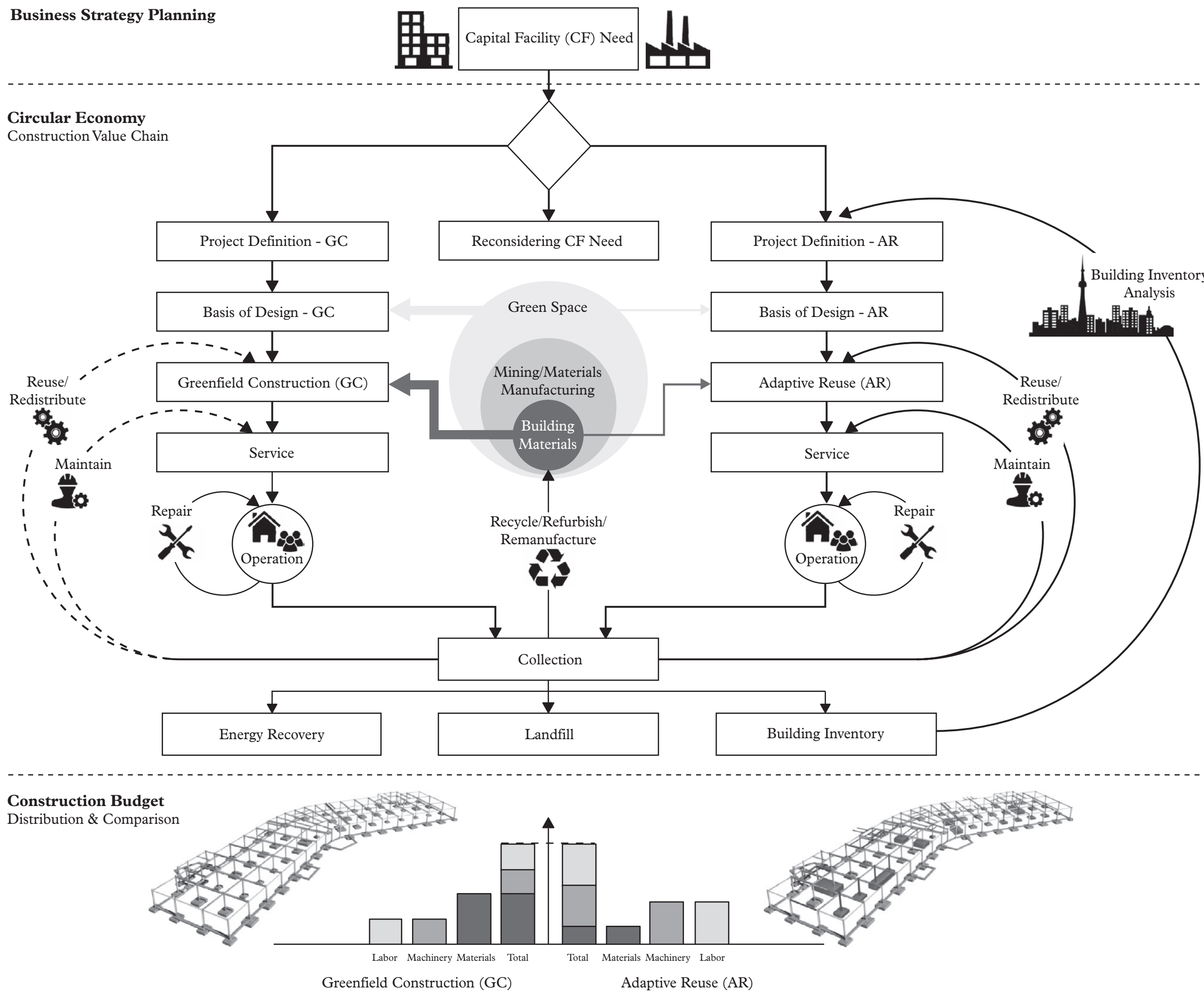

Figure 1. Circular economy principles in the construction value chain – Greenfield Construction (GC) vs. Adaptive Reuse (AR).

it is necessary to develop methods to predict the financial, social and environmental performance for adaptive reuse building projects. This makes it possible to understand and justify objectively when a building asset should be redeveloped using adaptive reuse.

This last point is important, because the methods and regulations needed rely on conventional intuitive planning procedures by experienced professionals in the construction industry to determine the scope and convenience of adaptive reuse projects. Intuitive planning procedures are easy to apply but can lead to suboptimal plans, and expertise is in short supply (Lin and Haas 1996). Many quantitative planning tools for adaptive reuse need to be developed (Figure 1), such as selective disassembly planning, and, among them a PDRI for reuse is perhaps the most important.

4. Developing a project definition rating index for adaptive reuse

The existing PDRI for buildings consists of 64 scope definition elements grouped into 11 categories in a weighted checklist format. Substantial revisions are required for adaptive reuse projects. For example, the basis of design is more focused on retrieval of existing information and the evaluation of the constraints that this process imposes. Also, the basis of design should assist in mitigating the risk stemming from issues such as technical feasibility, cost-effectiveness, environmental impact justification, logistics problems and permitting requirements. Therefore, we suggest some modifications to the PDRI for buildings, so that it could be used as a starting point for creating a PDRI for adaptive reuse projects. The modifications are organized into four groups according to planning objectives, as follows.

4.1. Basis of project decision

For the first group, the main objective is to develop the basis of project decision. It involves retrieval of the information necessary for understanding the project objectives according to circular building principles. Though the current PDRI includes an option for the evaluation of existing buildings, it does not include any requirement for the justification of the business strategy, owner philosophies and project requirements in terms of a circular economy. While a single building project would not justify developing an exhaustive macroeconomic analysis on these topics, we believe that a certain level of analysis is necessary in order to understand better the role of each particular project inside the built environment. This information is crucial in setting up the conditions for making strategic decisions aligned to circular economy principles, such as in the case of adaptive reuse of existing buildings instead of green-field building. This approach will be necessary when as a society we decide that all project objectives are not strictly commercial, and when social and environmental factors become monetized.

4.2. Basis of design

The second group of modifications has the objective of retrieving existing information for developing the project's basis of design, according to the imposed constraints. Once the basis of project decision has been completed, and the conditions for an adaptive reuse building project have been established, it is possible to develop the basis of design. Typically, for an existing building, most of the information in this matter is already documented. For adaptive reuse projects, the definition elements should be more focused on the affordability of retrieving the existing design documentation, verification of the existing condition's compliance according to the updated construction codes and analysis of the current physical conditions. This point is important, because a change in the scope and approach of the scope definition elements should change their weights in the overall PDRI score table. A comprehensive study is necessary to determine the element weights for the PDRI for adaptive reuse projects.

4.3. Recovery of economic and ecological value

The third group of modifications required has the objective of recovering as much of the economic, social and ecological value of a building as possible during the process of adaptive reuse. The potential benefits of adaptive reuse rely on the fact that it is possible to take away components from an obsolete building and then repair, reuse, remanufacture or recycle them. Some of the most important recovery EoL methods include design for disassembly, design for maintainability/serviceability, design for reuse, design for remanufacturing and design for recyclability (Smith and Hung 2015). For existing assets, complete design for disassembly is not possible, and the process is reduced to planning for disassembly. Planning for disassembly must play a key role in the adaptive reuse process, where the disassembly planning sequence (as well as the disassembly methods used to recover target components) has to be performed in an efficient way. The target components can be architectural, structural, mechanical or electrical, among others. The objectives should be to reduce building costs and to increase the building components' life cycle persistence. If the design for disassembly is too complex or time-consuming, the associated economic and environmental costs could be higher than installing new components. Therefore, it is necessary to incorporate a cost–benefit analysis for selective disassembly and demolition planning.

4.4. Execution approach

The execution approach definition must have the objective of evaluating the project scope elements that are necessary to fully understand the requirements of the owner's execution strategy, aligned to closed-loop cycle building methods. Groups of elements in the PDRI Execution Plan section include: (1) procurement strategy, (2) deliverables, (3) project control and (4) project execution plan. For the "project execution plan" group, the description of the scope elements in the PDRI has been delineated and weighted according to the most common and effective practices for green-field building. In a circular economy, the project execution plan faces different challenges due to the inclusion of new techniques for construction (green design methods), more stakeholders in sustainable development (environmental and social stakeholders) and new ways for trading building resources, such as materials, machinery use and labour, due to the increase in the valuation of the net environmental impacts that they produce from a lifecycle perspective.

In summary, redefining, re-weighting and selectively adding to, as well as deleting from, the current group of 64 scope definition elements of the PDRI tool would make it applicable for planning closed-loop building projects, such as adaptive reuse projects.

5. Concluding discussion

This article argues that project planning for capital projects must change as we shift from a linear to a circular economy. While understanding of the real value of the built environment in terms of economic, environmental and social dimensions has improved through technological development and research, more progress is required. In our linear economy, the economic dimension still drives capital project planning. The evidence suggests this situation is unsustainable, unbalanced and is reaching its physical limits.

Thus, a capital project planning framework is proposed for closed-loop cycle construction projects (Figure 1). We argue that the capital projects delivery phase for a circular economy should have distinct stages, decision gates, definition confidence categories and planning methods, such as selective disassembly, LCA monetization protocols and optimization methods. We also suggest a reference framework for required revisions to develop a planning tool for adaptive reuse projects. This framework identifies the project scope elements from the PDRI for buildings that must be modified in order to align them with circular building principles. Similarly, it is argued that some project scope elements should be completely modified according to the nature of the value chain in a circular economy. Finally, we defined another set of project scope elements that should remain without any changes in the approach. However, they should be investigated in order to demonstrate and validate the weight that represents their importance in the performance of a closed-loop cycle construction project. As well, validation is required to examine the hypothesis that the successful completion of a closed-loop cycle building project is positively correlated with the quality of the project definition during the pre-project planning phase. In other words, a well-defined project definition would correspond to a higher probability of project success in terms of sustainability.

In the capital project delivery phase of circular infrastructure, science-based, user-friendly and fit-for-purpose methods are needed to decide amongst green-field construction versus adaptive reuse, to develop pre-project planning for closed-loop cycle construction and to plan for the optimization of the benefits of adaptive reuse. Research and development in these areas is required to address the most important missing pieces of a circular economy value chain in construction. The merging of research in this field and the technological advances in the areas of Building Information Modeling (BIM), City Information Modeling (CIM), Internet of Things (IoT) and the enormous amount of data already available in virtual platforms will be the drivers to complete the reference framework proposed in this article.

Disclosure statement

No potential conflict of interest was reported by the authors.

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