UNIVERSIDADE FEDERAL DO PARANÁ

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APROXIMAÇÕES TEÓRICAS E INTERAÇÕES DAS RELAÇÕES PRÁTICAS ENTRE A ECONOMIA CIRCULAR E OS PRINCÍPIOS DA CONSTRUÇÃO ENXUTA

CURITIBA

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Dissertação apresentada ao curso de Pós-Graduação em Engenharia de Construção Civil, Setor de Tecnologia, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Mestre em Engenharia de Construção Civil.

Orientadora: Profa. Dra. Maria do Carmo Duarte Freitas
Coorientador: Prof. Dr. Sergio Fernando Tavares

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“When you wake up, think about winning the day. Don't worry about a week or a month from now -- just think about one day at a time. If you are worried about the mountain in the distance, you might trip over the molehill right in front of you. Win the day!” (DREW BREES, 2010)

RESUMO

A Indústria da Construção Civil é a que mais extrai recursos da natureza, além de gerar mais resíduos sólidos para o meio ambiente. Somente no Brasil, os resíduos de Construção e Demolição (C&D) contribuem para cerca de 63% da quantidade gerada diariamente. Isto ocorre principalmente pela mentalidade e cultura existente na Construção Civil de linearidade a partir do “tirar, fazer e dispor”, em que os recursos naturais são extraídos para apenas uma utilização e depois dispostos no fim de vida das edificações. Ao contrário deste ciclo, o conceito de Economia Circular (EC) vem ganhando interesse dentro da Construção Civil, que se baseia em um melhor gerenciamento de recursos e resíduos, com um maior foco na reutilização de materiais para que se mantenham em um ciclo fechado, evitando ao máximo a extração de novos recursos do meio ambiente. Similarmente, o conceito de Construção Enxuta (CE) busca melhorar o valor dos edifícios ao reduzir a geração de desperdícios e aumentar a produtividade na construção, sendo um conceito que já vem sendo pesquisado desde os anos 90. Apesar dessas similaridades de princípios, o estudo de ambos conceitos em conjunto ainda é incipiente, portanto, esta pesquisa teve o objetivo de pesquisar as interações entre os conceitos da Economia Circular dentro da Construção Civil e a Construção Enxuta. Para atingir os objetivos definidos, a pesquisa foi dividida em dois artigos. No primeiro artigo, uma revisão sistemática da literatura foi conduzida com o objetivo de identificar os recentes desenvolvimentos de pesquisa de como a Economia Circular está sendo utilizada dentro da Construção Civil, abrangendo 45 artigos. Foi possível a identificação de seis grandes áreas de pesquisa neste tema, suas lacunas de conhecimento, além de ser desenvolvida uma lista com práticas conhecidas da Economia Circular para a Construção Civil dividida de acordo com as fases do ciclo de vida da edificação. Na sequência desta pesquisa, foi desenvolvido o segundo artigo que tinha como objetivo encontrar as interações, positivas ou não, entre as práticas da Economia Circular para a Construção Civil e os princípios da Construção Enxuta. Para atingir este objetivo, foi utilizada uma análise de conteúdo, através da técnica de matriz de correlações, encontrando um total de 74 interações, sendo 70 positivas e 4 negativas. Através desses resultados foi possível identificar a prática da Economia Circular com mais interações com os princípios da Construção Enxuta, como também o resultado inverso, a fase do ciclo de vida da edificação com mais interações com os princípios da Construção Enxuta. Constatou-se que a maioria das práticas da Economia Circular para a construção civil tem a presença dos princípios da Construção Enxuta em sua concepção. A EC busca a eliminação de desperdícios dentro de sua cadeia de produção, incentiva que todos os materiais sejam de alguma maneira reaproveitados, preferencialmente que mantenham máximo valor pelo maior período de tempo possível, enquanto a CE quer a maior eficiência na produção com a eliminação das atividades que não agregam valor ao produto final. A similaridade entre os conceitos conduz a constatação que pensar Lean desde a fase de projeto conduza a promoção de práticas positivas da EC na edificação.

Palavras-chave: Economia Circular. Construção Enxuta. Construção Civil. Ambiente Construído.

ABSTRACT

The Civil Construction Industry is the one that most extracts resources from environment, in addition to generating the most solid waste. In Brazil, construction and demolition waste (C&D) accounts for about 63% of the amount generated daily. This is mainly due to the mentality and culture existing in the Civil Construction of linearity from the "take, make and dispose", in which the natural resources are extracted for only one use and then disposed at the end of life of the buildings. Unlike this cycle, the concept of Circular Economy (CE) has been gaining momentum in Civil Construction, based on a better management of resources and waste, with a greater focus on the reuse of materials so that they remain in a closed cycle, avoiding to the maximum the extraction of new resources from the environment. Similarly, the concept of Lean Construction (LC) seeks to improve the value of buildings by reducing the generation of waste and increasing productivity in construction, a concept that has been researched since the nineties. Despite these similarities in principles, the study of both concepts together it is still incipient, therefore, this research aimed to research the interactions between the concepts of Circular Economy within Civil Construction and Lean Construction. To achieve the defined objectives, the research was divided into two articles. In the first article, a systematic review of the literature was conducted in order to identify the recent research developments on how Circular Economy is being used within the Construction Industry, covering 45 articles. It was possible to identify six major areas of research on this theme, their knowledge gaps, in addition to developing a list of known practices from the Circular Economy for construction divided according to their phases of the building's life cycle. Following this research, the second article was developed aimed at finding the interactions, positive or not, between the practices of Circular Economy for construction and the principles of Lean Construction. To achieve this goal, a content analysis was used, using the correlation matrix technique, finding a total of 74 interactions, 70 of which were positive and 4 negatives. Through these results it was possible to identify the practice of Circular Economy with more interactions with the principles of Lean Construction, as well as the reverse result, the phase of the building life cycle with most interactions with the principles of Lean Construction. The CE seeks to eliminate waste within its production chain, encourages all materials to be reused in some way, preferably to maintain maximum value for the longest possible time, while the LC wants greater efficiency in production by eliminating activities that do not add value to the final product. The similarity between the concepts leads to the realization that thinking Lean from the design stage leads to the use of positive CE practices in a building.

Keywords: Circular Economy. Lean Construction. Construction. Built Environment.

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LISTA DE ABREVIATURAS OU SIGLAS

ACV	- Análise de Ciclo de Vida
BAMB	- *Building As Material Banks*
BIM	- *Building Information Modelling*
BMP	- *Building Material Passport*
BWPE	- *BIM-based Whole-life Performance Estimator*
C&D	- Construção e Demolição
CE (inglês)	- *Circular Economy*
CE	- Construção Enxuta
CO^2	- Dióxido de carbono
CoP	- *Community of Practice*
EC	- Economia Circular
EMF	- *Ellen MacArthur Foundation*
EN	- *European Standard*
EPC	- *Energy Performance Certificate*
EPD	- *Environmental Product Declaration*
GIS	- *Geographical Information System*
ICC	- Indústria da Construção Civil
IGLC	- *International Group for Lean Construction*
IMVP	- *International Motor Vehicle Program*
LC	- *Lean Construction*
LCA	- *Life Cycle Analysis*
PPGECC	- Programa de Pós-Graduação em Engenharia de Construção Civil
RBD	- *Reversible Building Design*
RDF	- *Resource Description Framework*
SJR	- *Scimago Journal & Country Rank*
TPS	- *Toyota Production System*
UFPR	- Universidade Federal do Paraná

SUMÁRIO

1 INTRODUÇÃO

A Indústria da Construção Civil (ICC) é responsável por um representativo número de extração de recursos naturais (REES, 1999). Além disso, a Construção Civil é responsável por um significativo consumo de energia para o processamento desses recursos extraídos da natureza, na transformação deles em materiais que serão utilizados na construção, expressivos valores de emissões de CO² para atmosfera e geração de resíduos sólidos (SOLANO, 2008).

A geração de resíduos da Construção Civil ocorre em todas suas fases do ciclo de vida de uma edificação (ESA; HALOG; RIGAMONTI, 2016). No entanto, a mais impactante é a etapa do fim de vida, em que cerca de 50% da geração de resíduos ocorre (KIBERT, 2008), devido à mentalidade e cultura da Construção Civil de dispor seus materiais da edificação ao final de sua vida útil, não dando muita atenção para a oportunidade de reutilizá-los.

Esta mentalidade da Construção Civil é baseada em uma economia linear, que é de "retirar, utilizar, dispor", em que os materiais são extraídos da natureza para utilização única na construção de edificações e ao final de vida são dispostos, sendo necessária a extração de materiais novos da natureza para manter esse ciclo linear (EMF, 2015).

Diante dessa cultura da Construção Civil de linearidade e a necessidade de reduzir os impactos negativos que ela traz para o meio ambiente, o conceito de Economia Circular (EC) ganha força e é desenvolvido como uma alternativa para o ambiente construído (POMPONI; MONCASTER, 2017).

O conceito de Economia Circular se baseia na melhoria do gerenciamento de seus recursos, em que Ellen MacArthur Foundation (2015) definiu como um sistema regenerativo que tem o objetivo de manter os materiais em seu mais alto valor em um ciclo fechado.

Na Construção Civil isto quer dizer que os materiais utilizados para a construção de edificações devem ser reutilizados e desconstruídos, funcionando como um banco de materiais para construções novas, mantendo esses materiais em ciclo fechado, evitando a retirada de novos recursos da natureza (HOPKINSON et al., 2019). E com este maior foco no reuso de materiais, existe uma grande redução na quantidade de resíduos gerados no final do ciclo de vida da edificação, algo que é um dos principais objetivos de outro conceito dentro da construção civil, a Construção Enxuta (CE).

Este conceito se baseia nos princípios do Pensamento Enxuto, que se originou das práticas de Produção Enxuta desenvolvidas na década de sessenta pelo Sistema de Produção Toyota (TPS, do inglês), e busca a eliminação de desperdícios nas atividades de processos para redução de tempos de ciclo, melhoria de qualidade e eficiência dentro da construção civil (AKANBI; OYEDOLAPO; STEVEN, 2019).

Womack e Jones (2004) definiram cinco princípios do Pensamento Enxuto que buscam a redução de desperdícios nas organizações: (1) Valor, que busca identificar o valor do produto do ponto de vista do cliente; (2) Fluxo de Valor, que é mapear o fluxo de produção deste produto; (3) Fluxo, que busca atingir um fluxo de produção sem desperdícios; (4) Puxar, em que a produção deva ser "puxada" pela demanda; e (5) Perfeição, que é a procura pela perfeição e melhoria contínua.

Essa similaridade entre os conceitos de Pensamento Enxuto e Economia Circular, com a busca da eliminação de desperdícios e aumento no valor do produto, faz com que a combinação de ambos tenha a tendência de produzir bons resultados (Nadeem et al., 2019). Dentro do campo da manufatura, Nadeem et al. (2019) desenvolveram uma estrutura para implementação de ambos os conceitos em conjunto ao relacionar seus princípios, buscando a mudança do modelo econômico linear para o "circular", a maximização do reuso de recursos em conjunto minimização de uso de materiais virgens e a redução de impactos negativos ao meio ambiente.

Dentro da construção civil, porém, não existem estudos que correlacionem ambos os conceitos com o foco no ambiente construído, mostrando o potencial de pesquisa para a exploração deste tema.

1.1 PROBLEMATIZAÇÃO

Embora exista similaridade entre os objetivos dos conceitos sustentáveis para construção civil, como o da Economia Circular, e Construção Enxuta, sua implementação em conjunto dentro das companhias do setor ainda sofre dificuldades (KORANDA et al., 2012). No caso da EC, devido às barreiras culturais, do mercado, regulatórias e tecnológicas (KIRCHHERR et al., 2018), enquanto a CE sofre com falta de liderança, má comunicação, falta de processos ou mecanismos concretos, resistência à mudança por parte dos trabalhadores e falta de compreensão do conceito (HINES; HOLWEG; RICH, 2004).

Dentro do campo acadêmico, a pesquisa correlacionando ambos os conceitos dentro da construção civil ainda é incipiente. Ao se pesquisar os termos “Circular Economy” e “Lean Construction” juntos no título, resumo ou palavras-chaves dentro das bases de dados do Science Direct, Scopus e Web of Science obtiveram apenas 1 resultado. Isto mostra a necessidade se ampliar a pesquisa e desenvolvimento da relação entre ambos os conceitos para a implementação na área.

A partir das similaridades iniciais entre os conceitos da Economia Circular e da Construção Enxuta, buscou-se responder à questão: Quais são as relações existentes entre as práticas da Economia Circular voltadas para a construção civil e o conceito de Construção Enxuta?

1.2 OBJETIVOS

1.2.1 Objetivo geral

O objetivo geral é analisar as aproximações teóricas e as interações das relações práticas, positivas ou negativas, existentes entre as práticas da Economia Circular e os princípios da Construção Enxuta dentro da Industria da Construção Civil.

1.2.2 Objetivo específicos

Para atingir o objetivo geral traçado, foram definidos os seguintes objetivos específicos:

- Investigar os recentes desenvolvimentos de pesquisa para a Economia Circular aplicada dentro da construção civil;
- Mapear as atividades e práticas existentes de aplicação dos conceitos da Economia Circular para a construção civil;

- Relacionar as práticas e interações, positivas ou negativas, da Economia Circular com os princípios da Construção Enxuta;
- Identificar uma sequência de práticas da Economia Circular dentro de um projeto de edificação, em todo ciclo de vida, que mais se assemelhem aos princípios da Construção Enxuta.

1.3 JUSTIFICATIVA

A Indústria da Construção Civil é responsável por trazer impactos negativos ao meio ambiente, devido à sua natureza exploradora de utilização de recursos para a criação de edifícios e infraestrutura, do consumo de energia para o processamento destes materiais, da quantidade de emissão de CO^2 e a geração de resíduos sólidos (SOLANO, 2008).

O impacto da construção civil na geração de resíduos sólidos é demonstrado, no Brasil, pela geração de 123 mil toneladas diariamente, cerca de 63% da quantidade total gerada por dia no Brasil (ABRELPE, 2018). Esta proporção é muito maior do que em outros lugares, como por exemplo a Europa, em que os resíduos de construção e demolição são de 25 a 30% do total gerado no continente (EUROPEAN COMMISSION, 2016) ou no Japão em que estes números são de 20% do total (MINISTRY OF THE ENVIRONMENT, 2014).

Outro fator a considerar é a destinação final desses materiais, que tenham potencial para serem reutilizados, reciclados ou descartados. Liu et al. (2017) afirmam que as duas primeiras opções se priorizadas diminui os impactos negativos ao meio ambiente, por retardar o descarte final dos materiais. Nesta ótica, ambos os conceitos de Economia Circular e Construção Enxuta se tornam relevantes na ICC.

O conceito de Economia Circular tem o potencial de interromper o ciclo linear, que retira recursos da natureza para uma utilização única antes da disposição final, proporciona oportunidades para a ICC, desde a redução da extração de recursos naturais e geração de resíduos sólidos até reduções no uso de energia e emissões de gases maléficos para a atmosfera (POMPONI; MONCASTER, 2017).

Já a Construção Enxuta tem o objetivo de reduzir os desperdícios que ocorrem dentro das etapas da construção ao eliminar as atividades do processo que não agregam valor ao produto final, a edificação (KOSKELA, 2000). Com isso, existe uma redução considerável da parcela de desperdícios físicos, que dentro dos canteiros de obras são os resíduos da construção.

Essa redução de resíduos gerados dentro da construção também tem grande impacto econômico. Em 2017 a ICC correspondeu a 5,2% do Produto Interno Bruto (PIB) do Brasil (IBGE, 2018), o que indica sua representatividade na economia brasileira. Apesar disso, muito dinheiro é gasto com desperdícios e perdas que ocorrem na fase de execução dentro do canteiro de obras (PALIARI, 1999). Além disso, a mentalidade de economia linear da Construção Civil tem impacto nas perdas, devido à alta extração de recursos da natureza, sempre utilizando materiais novos para a construção, sem seu reaproveitamento (EMF, 2015), mostrando a necessidade da modernização e mudança de paradigma desta prática atual.

Freitas (2009) afirma que a modernização do setor da construção civil apresenta diferenças em relação a outros setores e indústria, devido à sua variação de localidade dos canteiros de obras, falta de qualificação técnica da mão-de-obra, falta de empenho na busca por melhorias na produtividade, além da complexidade de implementação de tecnologias da informação dentro dos processos da construção. Diante disso, normalmente a inovação costuma ser difundida de maneira lenta dentro da Construção Civil (BIS, 2013).

Um estudo realizado em 2017 (MCKINSEY GLOBAL INSTITUTE, 2017) comparou a ICC com outros setores, como o de manufatura e automotivo, e mostrou que a produtividade dentro ICC está estagnada, sem sinais de melhora. BRISSI e DEBS (2019) sugerem que as razões para a dificuldade de implementação de inovação dentro da ICC são: (1) resistência histórica dentro da ICC e (2) falta de visão holística para resolver estes problemas.

Parte-se do pressuposto que ambos os conceitos desta pesquisa trazem argumentos que auxiliam na mudança de cultura. Primeiramente, o conceito de Economia Circular prevê melhoria no gerenciamento e controle de todas as fases do ciclo de vida da edificação, sendo necessário uma visão holística que envolve toda sua cadeia de suprimentos (ADAMS et al., 2017). Já dentro do Pensamento Enxuto, o princípio de atingir um fluxo de produção sem desperdícios é obtido por meio de uma rota de produção com visão holística de todo fluxo (GARNETT; JONES; MURRAY, 1998).

Devido ao grande impacto ambiental da construção civil, mostra-se a necessidade de sua modernização a partir o uso de novas tecnologias que auxiliem a redução dos impactos ambientais negativos (STURGES; EGBU; BATES, 1999). Observa-se que vêm ocorrendo um número crescente de pesquisas com foco na redução do uso de energia e eficiência energética (LEISING et al., 2018). Além de pesquisas que analisam os impactos da construção ao longo do ciclo de vida por meio das Análises de Ciclo de Vida (ACVs). Embora exista múltiplos casos de ACVs para construções, um pequeno número de estudos considera a integração com a Economia Circular (HOSSAIN; NG, 2018).

Diferentes atores dentro da Indústria da Construção Civil veem a evolução do conceito de Economia Circular como importante para aumentar a sustentabilidade das edificações (LEISING et al., 2018). Portanto é necessário o desenvolvimento de tecnologias que auxiliem a inclusão dos conceitos de Economia Circular em ACVs ou outras análises em fases de projeto.

Apesar desta necessidade, as práticas de Economia Circular ainda encontram muitas dificuldades de implementação dentro da Construção Civil, como o fato de a comunidade responsável pelos investimentos de construções ter o foco em um retorno de investimento mais rápido. Fato, que favorece relacionamentos transicionais dentro da cadeia de suprimentos, ao invés de relacionamentos de longo termo que possam trazer benefícios para o reuso de materiais (HART et al., 2019). Outros fatores como o baixo custo de materiais virgens, poucos e inconvincentes estudos de casos sobre modelos econômicos para a Economia Circular dentro do ambiente construído contribuem para a dificuldade de sua adoção (KIRCHHERR et al., 2018).

Dentro do Programa de Pós-Graduação em Engenharia de Construção Civil (PPGECC) da UFPR existe um histórico de pesquisas sobre a Construção Enxuta (VILLAS-BÔAS, 2004; HOFACKER, 2007; CARVALHO, 2008; ROMANEL, 2009; COELHO, 2009; WIGINESCKI, 2010; SATO, 2012), enquanto o tema da Economia Circular está começando a ser pesquisado, através da linha de pesquisa denominada “Soluções circulares no ambiente construído: Desafios e oportunidades das edificações como banco de materiais” iniciada em 2018 por Sergio Tavares.

Diante deste cenário, um estudo combinando estas práticas com os princípios da Construção Enxuta tem o potencial de facilitar sua implementação dentro da ICC. Além da busca de tornar mais compreensível suas similaridades e incentivar construtores a utilizarem práticas da Economia Circular que possuam os princípios da Construção Enxuta.

1.4 ESTRUTURAÇÃO DA DISSERTAÇÃO

Esta dissertação está dividida em seis capítulos, para melhorar apresentar a pesquisa desenvolvida e seus resultados obtidos.

O capítulo 1 é denominado Introdução, apresentando uma contextualização do tema a ser tratado dentro desta dissertação, a problematização encontrada, os objetivos gerais e específicos determinados para esta pesquisa, e a justificativa para realização deste estudo.

O capítulo 2 é chamado de Referencial Teórico, em que são abordados os conceitos teóricos dos temas envolvidos dentro desta pesquisa. Primeiramente são apresentados os conceitos de Economia Linear e Economia Circular, seguido do seu desenvolvimento dentro da construção civil. Na sequência são abordados os conceitos e princípios da Construção Enxuta, como também o conceito em que foi baseada, o Pensamento Enxuto.

O capítulo 3 é denominado de Encaminhamento Metodológico, onde é feito uma breve apresentação de como foi desenvolvida esta dissertação e qual o conteúdo de ambos os artigos desenvolvidos dentro desta pesquisa.

O capítulo 4 é a apresentação primeiro artigo desta dissertação, chamado de “*Circular Economy in the Construction Industry: A systematic literature review*” (“Economia Circular na indústria da construção civil: Uma revisão sistemática da literatura”). Neste artigo é desenvolvida a primeira etapa desta pesquisa, sendo descritos os métodos utilizados, resultados obtidos e uma discussão deles.

O capítulo 5 é a apresentação do segundo artigo desta dissertação, chamado de “*Interactions between Circular Economy practices for the Construction Industry and Lean Construction principles*” (“Interações entre práticas da Economia Circular para a indústria da construção civil e princípios da

Construção Enxuta”). Dentro deste artigo é realizado uma breve revisão da literatura dos temas abordados, seguido pela descrição do método utilizado, os resultados obtidos e uma discussão.

O capítulo 6 é chamado de Considerações finais. Discute-se as relações práticas, positivas ou negativas, existentes entre as práticas da Economia Circular dentro da construção civil e os princípios da Construção Enxuta, para melhorar a compreensão de suas similaridades. Finaliza com as conclusões obtidas desta pesquisa, ressaltando os resultados obtidos por meio dos objetivos traçados e são feitas propostas para estudos futuros.

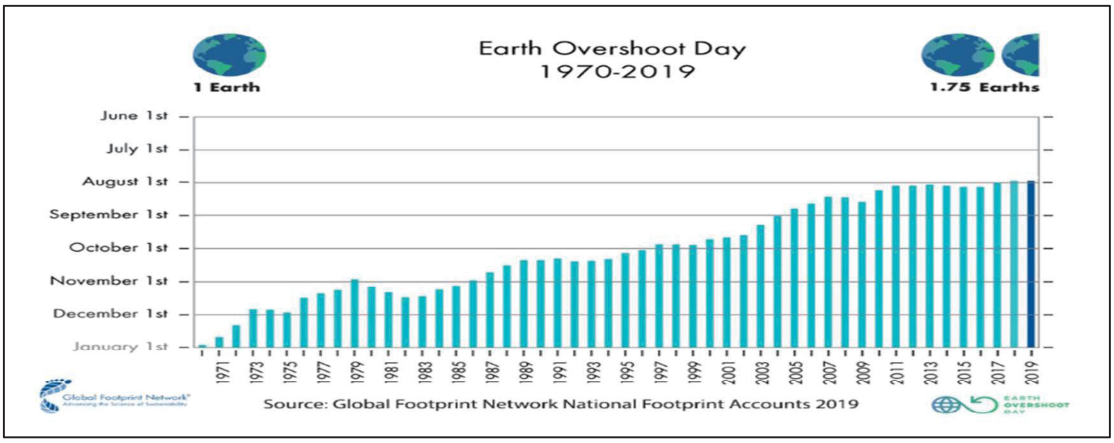
2 REFERENCIAL TEÓRICO

Esta seção trará o referencial teórico dos assuntos tratados na pesquisa, a Economia Circular e a Construção Enxuta. Além disso, aborda os conceitos que os precederam, como a Economia Linear, no caso da Economia Circular, e a Produção Enxuta e o Pensamento Enxuto, no caso da Construção Enxuta.

2.1 ECONOMIA LINEAR

Desde os tempos da revolução industrial, a economia mundial se baseia em uma mentalidade linear, de “retirar-produzir-dispor”, em que os materiais virgens são retirados da natureza, são processados para o uso do consumidor, vendidos, utilizados e então descartados como resíduos ou incinerados (EMF, 2012). Existe um consenso que está prática de consumo linear tem um efeito prejudicial na qualidade do meio-ambiente, igualdade social e estabilidade econômica a longo prazo (MILLAR; MCCAUGHLIN; BORGER, 2019). Desde o ano de 1971, a sociedade vem extraindo mais recursos por ano do que o próprio planeta consegue gerar, e em 2019 a extração de recursos ultrapassou este limite no dia 29 de julho, como mostra a FIGURA 1 (SARKIS, 2019).

FIGURA 1 - DIA EM QUE O MUNDO ULTRAPASSOU A QUANTIDADE DE RECURSOS GERADOS PELA NATUREZA ANUALMENTE



FONTE: Earth Overshoot Day (2019).

Este aumento no consumo de recursos naturais teve o suporte no avanço da economia em países avançados, em que o baixo custo dos recursos, em comparação com os custos de trabalho, criaram este sistema atual de gasto de recursos e geração de resíduos (MCKINSEY GLOBAL INSTITUTE, 2011). Além disso, a facilidade de obter novas matérias-primas e o baixo custo de dispô-las no meio ambiente, fez com que o reuso dos materiais produzidos não tenha ganho muito interesse das empresas (EMF, 2012).

O resultado destes fatores é o sistema chamado de Economia Linear, em que EMF (2012) listou as quatro principais perdas de recursos que acontecem durante a produção linear deste modelo:

Primeiramente ocorre a geração de desperdícios durante a cadeia de produção dos produtos. Esta perda ocorre normalmente durante as fases de extração, transporte, processamento dos produtos até o consumidor final. Especialmente na cadeia produtiva de comida, desperdícios ocorrem em diversas etapas: devido à pestes, baixa eficiência da agricultura, vazamentos durante o transporte, perdas no armazenamento, e produtos que não são consumidos pelo consumidor final (GUSTAVSSON; CEDERBERG; SONESSON, 2011).

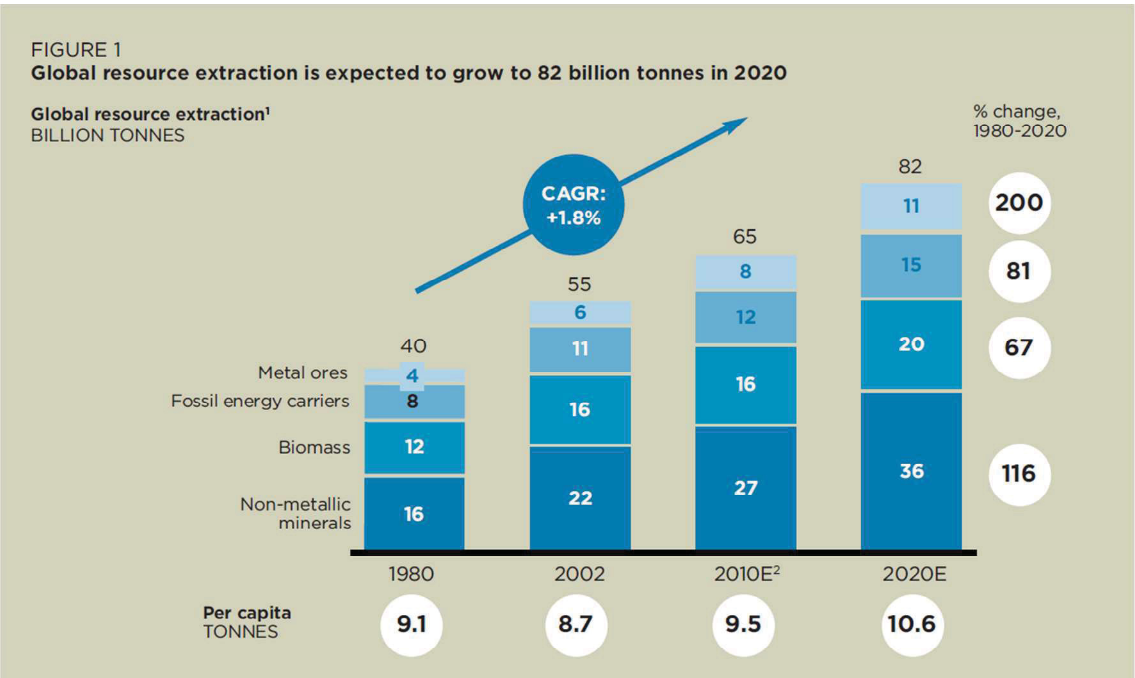
Outra grande fonte de perdas são os desperdícios no final da vida útil dos materiais, que ocorre quando os produtos são descartados depois do uso pelo consumidor, ao invés de ser reaproveitado. Na Europa em 2016 cerca de 2,5 bilhões de resíduos foram gerados, sendo apenas 38% reaproveitado de alguma maneira, seja por reuso, reciclagem ou compostado (EUROSTAT, 2019).

Além das perdas físicas citadas, este processo linear causa grande gasto de energia. Durante as fases de extração, transporte e processamento dos produtos ocorre o maior gasto de energia, por isso as empresas vêm procurando aumentar os níveis de reciclagem e reuso de materiais virgens, já que os processos de incineração e reciclagem recuperam parte desta energia, e o reuso diminui consideravelmente a energia de extração dos recursos da natureza (EMF, 2012).

Por fim, o relatório da *Ellen MacArthur Foundation* (EMF) de 2012 considera a erosão dos serviços “prestados” pelos ecossistemas como um grande perigo deste modelo linear predominante. Estes serviços são aqueles que ocorrem dentro de ecossistemas e auxiliam o bem-estar e vivência dos seres humanos, como a geração de oxigênio, absorção de dióxido de carbono, regulamentação dos ciclos de chuvas, entre outros benefícios que as florestas, por exemplo, trazem para os seres vivos. Em pesquisa realizada em 2005 pelo *Millennium Ecosystem Assessment*, descobriu que 15 de 24 ecossistemas estudados estão sendo degradados devido à falta de sustentabilidade, ou seja, estes ecossistemas não estão conseguindo produzir a quantidade necessárias de recursos para se manter sustentáveis devido ao grande número de extrações destes recursos pelos seres humanos (EMF, 2012).

Como mais uma complicação deste modelo linear de produção de produtos, a extração dos recursos naturais vêm crescendo nas últimas décadas e projeções do início da década de 2010 previam que estes números tendiam a continuar crescendo. A FIGURA 2 mostra que em previsão para o ano de 2020, o valor de recursos naturais extraídos será o dobro do que foi extraído a 40 anos atrás e cerca de 25% maior do que o valor de 2010. Além disso, o valor de minérios metálicos, um tipo de recurso não renovável, tende a crescer cerca de 200% do valor de 1980.

FIGURA 2 - EXTRAÇÃO DE RECURSOS NATURAIS



FONTE: EMF (2012).

Além dos impactos ambientais que esta mentalidade linear trás, este modelo pode desequilibrar o desenvolvimento econômico dos países. Uma grande dependência na extração de recursos naturais para produção de bens consumíveis torna as empresas reféns aos valores de commodities, que desde o início dos anos 2000 teve uma tendência no aumento em seus valores (EMF, 2012). Esta tendência faz as empresas repensarem seus modelos de negócios, buscando implementar cada vez mais materiais reutilizados ou reciclados, procurando fugir do modelo linear e migrar para um modelo de uso de recursos circular.

2.2 ECONOMIA CIRCULAR

Dentro desta tendência das empresas buscarem o maior aproveitamento de seus recursos, o conceito de Economia Circular ganhou bastante força na última década através de diversos relatórios publicados pelo instituto *Ellen MacArthur Foundation* (EMF, 2012, 2013, 2014, 2015) que define a EC como "uma economia que é restauradora e regenerativa por design e objetiva em manter os produtos, componentes, e materiais em seus maiores níveis de utilidade e valor por todo tempo, distinguindo os ciclos técnicos e biológicos" (EMF, 2015).

Apesar deste conceito ter ganho força apenas recentemente, suas origens são encontradas em outros conceitos desenvolvidos durante o último século (LEISING; QUIST; BOCKEN, 2018). Até antes disso, Senhem e Pereira (2019) citam que o conceito de Economia Circular apareceu pela primeira vez em 1848, quando R.W. Hofman, presidente da *Royal Society of Chemistry*, disse: "... em uma fábrica de produtos químicos ideal, não há nenhum desperdício, mas apenas produtos. Quanto melhor uma fábrica real faz uso de seus resíduos, quanto mais se aproxima de seu ideal, maior é o lucro".

Leising, Quist e Bocken (2018) descreveram que, o conceito de Economia Circular dentro do século XX começou com Boulding (1966), como um "sistema ecológico cíclico em que é capaz de reprodução contínua de formas de materiais mesmo que não possa escapar ter entrada de energia", sendo que as fontes de energia, água e materiais deveriam ser gerados através da reutilização e reciclagem de materiais para que fosse possível atingir um futuro sustentável (SENHEM; PEREIRA, 2019).

Na década de 1970, o professor americano John T. Lyle lançou um desafio para seus alunos de graduação para desenvolver ideias para uma sociedade em que as atividades diárias eram baseadas dentro de um valor de viver dentro dos limites dos recursos renováveis disponíveis, sem degradação do meio ambiente. Este pensamento deu origem ao conceito de Design Regenerativo, em que todos sistemas deveriam ser orquestrados de maneira regenerativa, algo adotado dentro do conceito de EC (EMF, 2012).

Ainda dentro dos anos 70, o arquiteto Walter Stahel desenvolveu uma visão de uma economia em ciclos fechados e os impactos que traria na criação de empregos, competitividade econômica, economia de recursos e prevenção de desperdícios, que ficou conhecida como Economia de Desempenho (EMF, 2012). Esta visão contemplava as ideias de prolongamento da vida dos produtos, através da reparação, por meio da manufatura, dos produtos (SENHEM; PEREIRA, 2019).

Uma das maiores influências para o conceito da Economia Circular é o conceito de *Cradle to Cradle* de McDonough e Braungart (2002), que tem o foco no fluxo em ciclos fechados e um novo design de produtos (ÜNAL et al., 2019). Este conceito desenvolvido no início do século XXI considera todos os materiais envolvidos nos processos industriais e comerciais como nutrientes, diferenciando-os entre ciclos de nutrientes técnicos e biológicos (EMF, 2012).

Dentro do ciclo biológico dos nutrientes, os materiais são devolvidos ao meio ambiente no final do seu ciclo de vida como forma de composto, que ajudarão novos produtos a serem criados. Já no ciclo técnico dos nutrientes, os materiais que não são utilizados dentro da vida útil do produto podem ser reprocessados para inclusão dentro de um novo produto e continuar o ciclo (SENHEM; PEREIRA, 2019).

Esta visão tem ênfase na composição particular de cada produto, como por exemplo na indústria da tecnologia, em que os produtos estão sujeitos a melhorias frequentes, portanto a durabilidade do produto não seria uma estratégia otimizada de seu design. Neste caso, seria preferível que o produto seja projetado para que a desmontagem e recuperação de seus componentes ocorra de maneira mais simples, auxiliando as possíveis melhorias do produto ou a montagem de uma nova geração dos mesmos (EMF, 2012).

Outro conceito por trás da Economia Circular é o da Ecologia Industrial, em que os sistemas industriais devem se basear em ecossistemas naturais. Dentro da natureza, qualquer recurso útil e disponível será utilizado por algum organismo; materiais e energia tendem a circular dentro de uma complexa cadeia de interações; e plantas viram alimentos para os animais, que morrem e se decompõe, iniciando o ciclo novamente (EL-HAGGAR, 2007). Este pensamento busca a criação de ciclos fechados de processos, em que os desperdícios servem como entrada de novos recursos, eliminando a ideia de desperdícios como indesejáveis (EMF, 2012).

Ao se basear nos conceitos desenvolvidos nos últimos cinquenta anos, a Economia Circular incorpora algo de cada um deles. EMF (2012) citou os cinco principais princípios em que a EC se baseia. O QUADRO 1 mostra o resumo destes princípios.

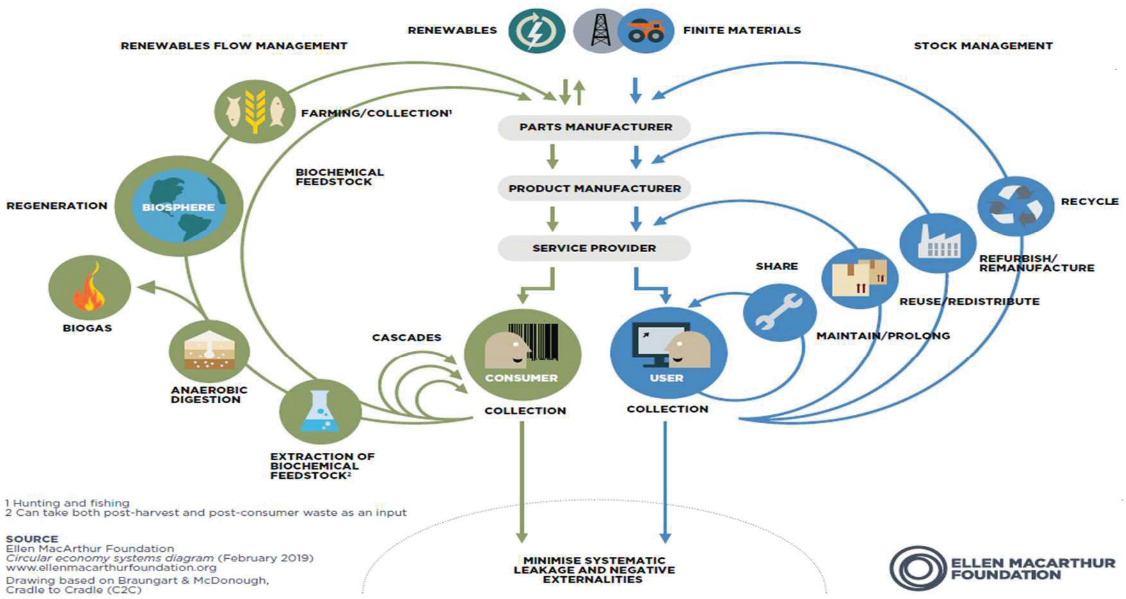
QUADRO 1 - PRINCIPIOS DA ECONOMIA CIRCULAR

Princípio	**Definição**
Projetar sem desperdícios	O projeto de produtos deve ser feito com a ideia de não existir desperdícios, sejam eles dentro do ciclo biológico ou técnico. Este projeto deve levar em consideração que os nutrientes biológicos não serão tóxicos e poderão ser simplesmente compostado. Já os nutrientes técnicos deverão ser projetados para que sejam reutilizados com o menor uso possível de energia e a maior retenção de valor possível.
Construir resiliência através de diversidade	Desde a revolução industrial existiu um foco no desenvolvimento de produtos uniformes, porém para que os sistemas atuais sejam mais resilientes aos problemas externos, os produtos deverão ser projetados com o foco na adaptabilidade dentro dos sistemas. Isto é o que ocorre nos ecossistemas naturais, onde os sistemas se adaptam aos ambientes através da infinidade de diversidade e complexidade existentes.
Utilizar energia de fontes renováveis	O uso de energia provenientes de fontes renováveis deve ser o objetivo dos sistemas, habilitado por um nível de necessidades de energia mais baixo dentro de um sistema regenerativo.
Pensamento em "sistemas"	Os elementos devem ser considerados de acordo com seus relacionamentos com a infraestrutura, meio ambiente e contextos sociais. Este tipo de pensamento enfatiza o fluxo e conexões ao longo do tempo, possibilitando um sistema regenerativo, ao invés de focar em uma ou outra parte em um pensamento em curto prazo.
Desperdício é comida	Dentro do ciclo biológico dos nutrientes, a possibilidade de reintroduzir produtos e materiais de volta ao meio ambiente através de ciclos regenerativos fechados é uma das essências da Economia Circular. Já no ciclo técnicos dos nutrientes, melhorias na qualidade dos produtos é possível através da chamada reutilização criativa, ou *Upcycling*.

FONTE: Adaptado de EMF (2012).

Recentemente a *Ellen MacArthur Foundation* publicou um relatório com o foco na maneira em que a Economia Circular pode auxiliar na mitigação das mudanças climáticas no mundo (EMF, 2019), em que mostra sua mais recente compreensão do sistema envolvido dentro da EC, presente na FIGURA 3.

FIGURA 3 - CICLO DA ECONOMIA CIRCULAR



FONTE: EMF (2019).

Este diagrama vêm sendo desenvolvido desde o primeiro relatório lançado pelo instituto (EMF, 2012) e é baseado no conceito de ciclo de nutrientes biológicos e técnicos de McDonough e Braungart (2002), sendo atualizado com cada nova publicação da organização.

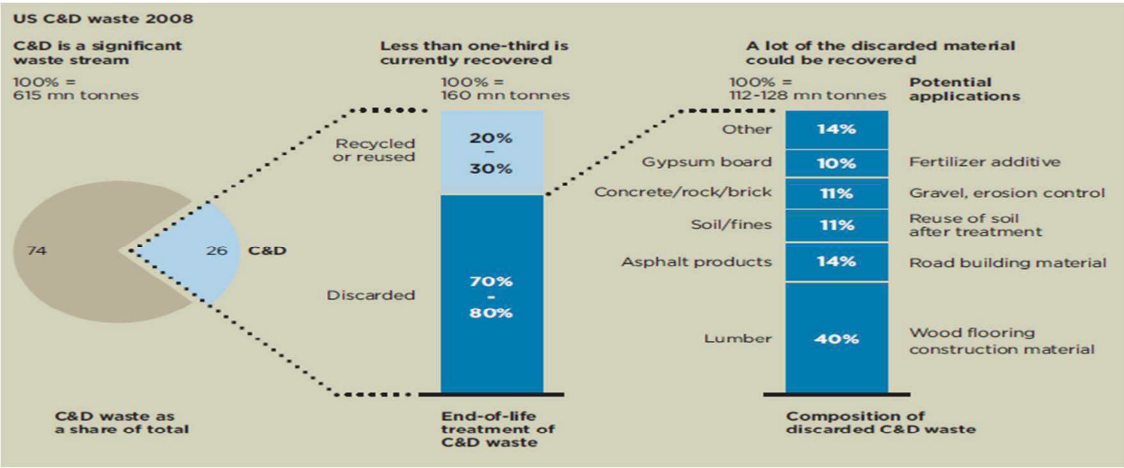
Este sistema mostrado na FIGURA 3 pode ser dividido em três etapas. Primeiramente o foco é na preservação e no realce dos recursos naturais existentes, através do controle de fontes de recursos renováveis.

Na sequência o ciclo dos produtos é dividido nos ciclos biológicos e técnicos, em que existe uma busca pela otimização dos recursos existentes, através da circularidade dos componentes e materiais, procurando os manter em seus mais altos valores durante todo ciclo. Por fim, deve ser promovida a eficiência deste sistema ao levar em conta no projeto as externalidades negativas do sistema.

2.3 ECONOMIA CIRCULAR DENTRO DA CONSTRUÇÃO CIVIL

Dentro do contexto da Indústria da Construção Civil, o cenário não é tão diferente do citado anteriormente. No ano de 2008 os Estados Unidos geraram 615 milhões de toneladas de resíduos sólidos provenientes da Construção e Demolição (C&D), nos quais apenas 26% foram reciclados ou reaproveitados de alguma maneira. A FIGURA 4 mostra que dos 74% de resíduos que foram descartados, todos possuem aplicações potenciais para sua reutilização.

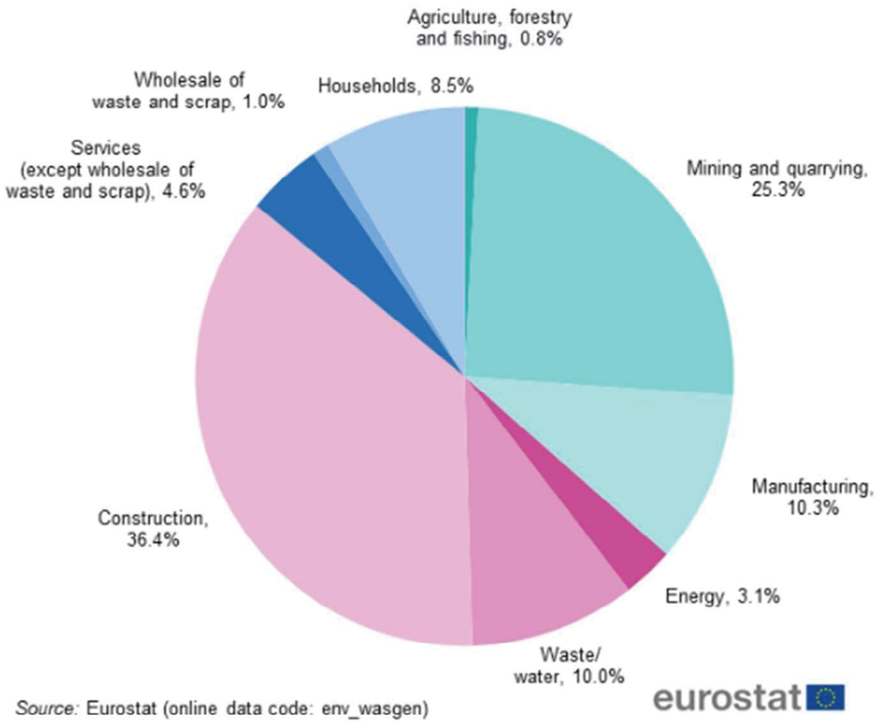
FIGURA 4 - DESTINAÇÃO FINAL DOS RESÍDUOS SÓLIDOS GERADOS NOS EUA EM 2008



FONTE: EMF (2012).

Além de um baixo nível de reaproveitamento dos resíduos sólidos gerados, a ICC tem grande impacto negativo na geração dos resíduos por ser indústria com maiores índices de gerações. Como pode ser visto na FIGURA 5, em 2016 a ICC gerou cerca de 36% da quantidade total de resíduos gerados dentro da Europa, de um valor total de 2,5 bilhões de toneladas (EUROSTAT, 2019).

FIGURA 5 - PORCENTAGEM DE RESÍDUOS GERADOS NA EUROPA POR ORIGEM



FONTE: Eurostat (2019).

A geração de resíduos dentro da construção civil ocorre em todas fases do ciclo de vida da edificação, porém a fase mais impactante é o final da vida útil, onde cerca de 50% dos resíduos são gerados (KIBERT, 2008).

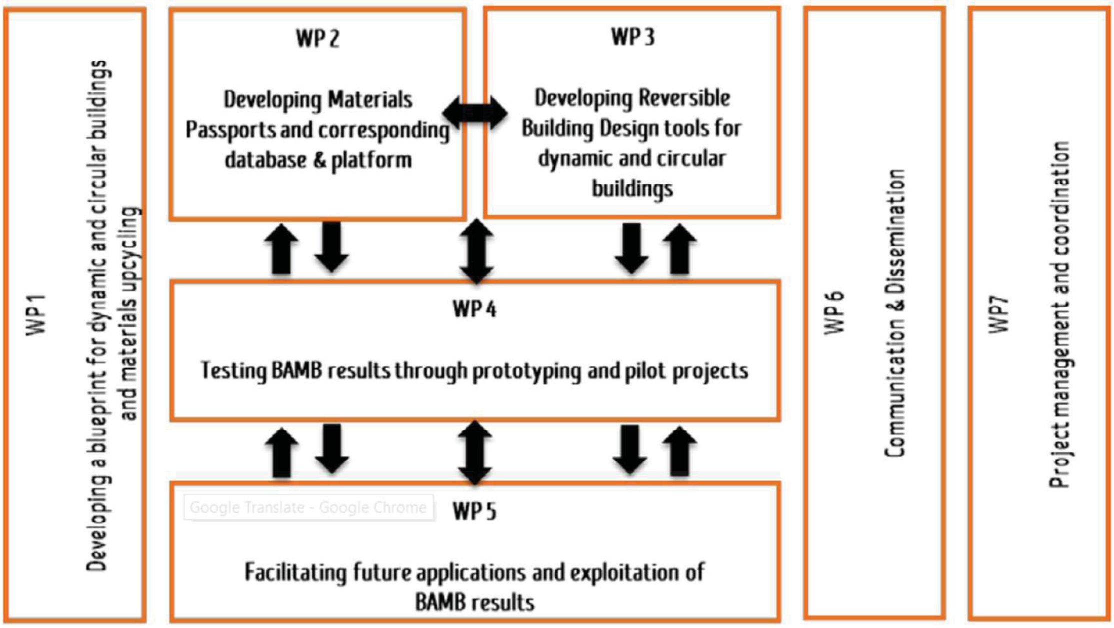
Isto ocorre, pois, a construção civil também utiliza um modelo de economia linear, em que ocorre a extração de materiais virgens do meio ambiente para a produção do materiais e estruturas da edificação, que são então utilizados no canteiro de obras para a montagem e construção da edificação, de maneira em que fica impossibilitada a sua desmontagem, tornando-os obsoletos ao final da vida útil do edifício, sendo necessária sua disposição final em aterros ou serem incinerados, juntos com todos os desperdícios e resíduos que foram gerados nas outras fases do ciclo de vida (MAGIALARDO; MICELLI, 2018).

A partir deste modelo existente que surgem os impactos negativos para o meio ambiente, muitas pessoas e organizações envolvidas com o ambiente construído acreditam que o uso do conceito de Economia Circular para a construção civil seja um passo importante para o aumento de valor financeiro, social e ambiental das edificações através do uso da visão sistemática de todo ciclo de vida e aplicação de novas tecnologias dentro deste conceito (POMPONI; MONCASTER, 2017).

Na busca da adaptação do conceito de EC para a ICC, foi criado em 2015 o projeto BAMB – *Building As Material Banks* (Edifícios como banco de materiais), que consiste em 16 parceiros de 8 países europeus, com o objetivo de possibilitar uma transição do sistema linear tradicional das edificações para o uso de soluções circulares na construção civil (BAMB, 2016). Este projeto leva em consideração o conceito da EC de manter o máximo valor possível dos produtos dentro do ciclo de vida das edificações, através da criação de projetos e cadeias de valor circulares, procurando diminuir a produção de desperdícios e uso de recursos naturais virgens.

A estrutura deste projeto está dividida em 7 etapas, que são sustentadas pelo desenvolvimento de dois conceitos principais da EC para a construção civil: Passaportes de Materiais e Projetos de Edificações Reversíveis. A FIGURA 6 mostra a sequência destas etapas.

FIGURA 6 - ETAPAS DO PROJETO BAMB



FONTE: BAMB (2016).

Primeiramente ocorre o desenvolvimento do estado de arte das soluções existentes para edifícios circular e reciclagem de materiais. Na sequência as etapas 2 e 3 ocorrem concomitantemente, com o desenvolvimento de práticas e ferramentas dos dois conceitos que sustentam este projeto. A próxima etapa é responsável por testar os resultados obtidos nas fases anteriores, seguido pela exploração destes resultados e proposição de melhorias para as aplicações desenvolvidas. As últimas duas fases consistem na comunicação e disseminação das descobertas, sendo finalizado pela inclusão dos resultados no gerenciamento de projetos.

O primeiro dos conceitos que sustentam este projeto é o desenvolvimento de Passaportes de Materiais, que é definido por BAMB (2019b) como "instrumento que oferece uma plataforma e repositório para armazenar, conectar distribuir informações relevantes dos materiais nas edificações para os atores relevantes durante a cadeia de valor". Grande parte da informação sobre os materiais de uma edificação são dispersos ou não estão disponíveis, sendo uma importante causa de criação de desperdícios nas construções (BAMB, 2016).

A criação e desenvolvimento desses passaportes é uma ferramenta de suporte para a circularidade das edificações, com o foco na recuperação ao final do ciclo de vida e maximização do valor desses materiais (LUSCUERE, 2017). Isto traz a possibilidade de oferecer oportunidades para a recuperação e reutilização dos materiais de construção dentro de toda cadeia de produção da ICC, além de servir como um instrumento de mercado que pode promover o aumento de qualidade, valor e segurança dos materiais em busca da reutilização em ciclos fechados (BAMB, 2016).

O outro conceito por trás do projeto BAMB é o desenvolvimento de projetos para edificações reversíveis. Para que isso seja atingido, o relatório inicial do projeto BAMB (2016) descreveu 3 ferramentas que serão desenvolvidas durante o projeto para facilitar a criação de projetos que consideram os materiais da edificação como reversíveis dentro do ciclo fechado de materiais: (1) Ferramenta de potencial de reuso, que servirá para verificar a possibilidade técnica da reutilização de materiais e estruturas da edificação; (2) Ferramenta de capacidade de transformação; que avaliará o potencial existente para adaptação das edificações existentes para outros usos; e (3) Protocolos para projetos de edificações reversíveis, que irá integrar as duas ferramentas iniciais, para facilitar os projetistas nas tomadas de decisões durante a fase de concepção dos projetos.

O projeto BAMB está na fase 5, tendo sido feita a publicação em 2019 de uma estrutura de políticas, regulações e padrões para a Economia Circular dentro do ambiente construído (BAMB, 2019a). Além disso, diversos relatórios sobre o desenvolvimento de ambos conceitos das fases 2 e 3 foram publicados nos últimos 3 anos (BAMB, 2017a, 2018a, 2019b, 2019c, 2019d, 2019e, 2019f) e também sobre os testes realizados em cima dos projetos pilotos desenvolvidos (BAMB, 2017b, 2018b, 2019g).

A partir do estudo do conceito da Economia Circular é constatado suas similaridades com o conceito de *Lean* (Nadeem et al., 2019), portanto nas seções seguintes do Referencial Teórico são abordados os conceitos de *Lean* desde as suas origens, até o uso dentro da construção civil, através da Construção Enxuta.

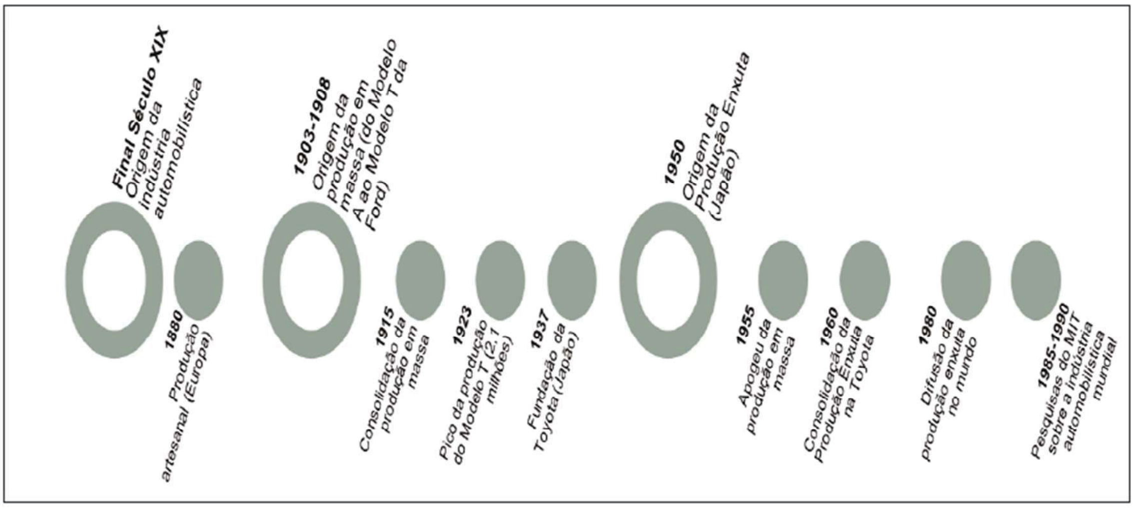
2.4 PRODUÇÃO ENXUTA

Desde o início do século XX, a produção em massa dentro das indústrias foi o modo produtivo predominante, principalmente no setor automotivo, impulsionado pelo americano Henry Ford. Este sistema se opôs ao sistema de produção artesanal, mais utilizado na época, ao utilizar produtos padronizados, com altos volumes e baixos custos de produção (OHNO, 1997).

A partir do final da segunda guerra mundial, a empresa automobilística Toyota introduziu um sistema diferente do criado por Henry Ford. Nesta época, o Japão passava por um período de crise econômica e restrições de mercado. Diante disso, Taichii Ohno desenvolveu um sistema de produção baseado na eliminação de desperdícios, que se tornou mais eficiente, ágil, inovador e flexível, comparado ao sistema de produção em massa (WOMACK; JONES; ROOS, 1992). Esse sistema desenvolvido no Japão ficou conhecido como Sistema Toyota de Produção (TPS, sigla do inglês) e consistia em um gerenciamento de trabalho para atender aos clientes no menor tempo possível, na mais alta qualidade e com o menor custo possível (WOMACK; JONES, 2004).

Esse sistema de produção deu origem ao termo Lean, ou do português Enxuto, que originalmente representou um sistema produtivo que utilizava menos recursos. Este termo começou a ser utilizado após um programa desenvolvido no MIT publicou uma série de pesquisas realizadas no final da década de 1980 sobre a indústria automobilística, denominado *International Motor Vehicle Program* (IMVP) (WOMACK; JONES; ROOS, 1992). A FIGURA 7 mostra uma linha do tempo dos sistemas de produções até o desenvolvimento do termo Lean.

FIGURA 7 - LINHA DO TEMPO DOS SISTEMAS PRODUTIVOS NA INDÚSTRIA AUTOMOBILÍSTICA



FONTE: FREITAS (2018).

Dentro da indústria automobilística o sistema ficou conhecido *como Lean Production* (Produção Enxuta). Womack e Jones (2004) definiram a Produção Enxuta como um sistema de produção que é “enxuto” por utilizar menores quantidades em todos os sentidos, quando comparado ao sistema de produção em massa: metade do esforço dos operários, metade de espaço para fabricação do produto, metade do investimento em ferramentas, metade de horas de planejamento, entre outros. Esse sistema também requer menos da metade dos estoques atuais, ao comparado com a produção em massa, e resulta em bem menos defeitos, com uma quantidade crescente e variada de produtos.

A forma de organizar os processos na linha de produção produzia mudança na forma de pensar dos profissionais – fato que deu origem ao termo “*Lean Thinking”* (Pensamento Enxuto) (FREITAS, 2018).

2.5 PENSAMENTO ENXUTO

A partir do sistema desenvolvido pela Toyota que deu origem à Produção Enxuta, Womack e Jones (2004) introduziram o conceito de Pensamento Enxuto, que visa a aplicação da filosofia Enxuta em empresas de qualquer setor, definindo-o como “uma forma de especificar valor, alinhar na melhor sequência as ações que criam valor, realizar essas atividades sem interrupção toda vez que alguém as solicita e realiza-las de forma cada vez mais eficaz”. Diante deste conceito, Womack e Jones (2004) também definiram os cinco princípios básicos do Pensamento Enxuto:

a) Valor: O primeiro princípio deste conceito é um que está presente em todos os outros quatro. Este princípio refere-se à identificação do valor que o produto final possui para o cliente final. Diante disso este conceito busca a especificação do valor a partir da perspectiva do cliente que irá consumir o produto ou serviço.

b) Cadeia de valor: Este princípio se refere ao mapeamento das atividades presentes na cadeia produtiva que agregam valor ao produto final, buscando a eliminação destas atividades e uma otimização daquelas que agregam valor. Dentro disto, estas atividades podem ser divididas em três diferentes grupos: (1) atividades que realmente agregam valor ao produto final; (2) atividades que não agregam valor, mas são necessárias durante o processo; e (3) atividades que não agregam valor e geram desperdícios, devendo ser eliminadas do processo.

c) Fluxo: Dentro da cadeia de valor encontrada para a produção, o fluxo das atividades deve ser contínuo, sem interrupções devido à desperdícios ou estoques intermediários. Este fluxo contínuo traz diversos benefícios para a produção, como a redução dos tempos de ciclos e redução de atividades de transportes que traziam desperdícios para o fluxo.

Essa mudança no fluxo demanda uma modificação na estrutura das organizações, com maior foco em equipes integradas do que departamentos separados. Para atingir este objetivo, as seguintes etapas devem ser seguidas: (1) tratar o processo de maneira completa, rastreando-o do início ao fim; (2) eliminar os entraves do fluxo contínuo da produção; e (3) reavaliar os métodos e ferramentas utilizados na produção, visando a eliminação das interrupções e desperdícios ao longo do caminho.

d) Puxar: O Pensamento Enxuto introduz também uma mudança de mentalidade no quesito da produção de estoques. Enquanto na produção em massa o objetivo é a criação de um grande número de produtos no estoque para serem disponibilizados aos clientes, o Pensamento Enxuto busca a redução de estoques desnecessários, considerados desperdícios.

Nesta mentalidade, a produção dos estoques é “puxada” pelo cliente final, sendo apenas inicializada a produção do produto final após o pedido pelo cliente. Nesta cadeia sequencial o pedido vêm da atividade final até a atividade inicial, sendo um processo contrário do tradicional, eliminando os estoques intermediários e sendo realizado a produção apenas da demanda existente, evitando desperdícios.

e) Perfeição: Com a adoção dos quatro primeiros princípios do Pensamento Enxuto, a empresa obterá redução dos tempos de produção, de recursos necessários, esforços, defeitos e erros durante o processo, permitindo que seja feita uma análise do ciclo existente para que exista uma busca contínua para a perfeição do processo.

A seguir tem-se o conceito da Construção Enxuta que é derivado da Produção Enxuta do setor automobilístico, onde este conceito foi implementado com sucesso, e instituições como o IMVP servem como referências para a construção civil (SATO, 2012).

2.6 CONSTRUÇÃO ENXUTA

O processo de produção tradicional da construção civil é baseado no modelo de conversão. Neste modelo o produto final, a edificação, é resultado de diversas conversões de materiais e atividades, e pode ser dividido hierarquicamente em subprocessos, que também são de conversão (SCHEER et al., 2008).

Este modelo, porém, apresenta resultados incorretos e uma realidade não condizente com o processo real quando é utilizado para modelar o processo global da construção, com o objetivo de analisar e gerenciar as operações da produção da construção civil (SHINGO, 1988).

O problema para a construção civil desse modelo é que não é feita a diferenciação das atividades de conversão, que agregam valor, das atividades de fluxo, que não agregam valor, além de que os fluxos presentes dentro do canteiro de obras são complexos. Existem diversos fluxos onde os trabalhadores realizam diferentes atividades em diferentes locais ao redor da edificação em construção, aumentando a complexidade dos fluxos envolvidos na produção (BERTELSEN et al., 2007).

Bernardes (2001) citou também outros problemas ao utilizar este modelo de conversão para a construção civil. Primeiramente os fluxos físicos das atividades da construção não são abordados dentro deste modelo, porém o que se encontra na realidade é que a maioria dos custos de produção dentro do canteiro de obras é proveniente destes fluxos. Além disso, o controle da construção tende a focar no controle de subprocessos, ignorando um controle no processo global, portanto reduzindo os impactos positivos no processo completo. Por fim, o autor cita que a não consideração dos requisitos do cliente final faz com que os produtos finais sejam inadequados, por não atender as características exigidas pelo cliente.

Koskela (1992) estudou os problemas deste modelo de conversão para a construção civil, e introduziu conceitos bem sucedidos da Produção Enxuta, como *Just-in-Time* e *Total Quality Control*, focados na construção civil. Esta aplicação dos conceitos dentro da ICC depois ficou conhecida como Construção Enxuta, e buscou compreender as atividades da construção como fluxos de processos materiais e de informação, onde a eficiência do processo dependerá das atividades de conversão e também de como os fluxos existentes entre elas serão tratados (SCHEER et al., 2008).

Diante deste pensamento de considerar as atividades de conversão e os fluxos entre elas no processo global da produção da construção, Koskela (1992) desenvolveu uma série de onze princípios sobre a adoção do conceito da Produção Enxuta para a construção civil:

a) Redução das atividades que não agregam valor: Segundo Koskela (1992) as atividades dentro do canteiro de obras podem ser divididas em dois grupos: (1) atividades de conversão de material ou informação que são requisitos do cliente final e (2) atividades que não agregam valor ao cliente, utilizando tempo, recursos ou espaço.

Dentro desta divisão, deve-se então buscar a eliminação de todas atividades que não agregam valor, sendo a eliminação destas atividades divididas em três grupos: (1) redução ou eliminação das perdas referentes à inspeções, movimentações e esperas durante o processo, consideradas críticas pelo autor; (2) falta de informação sobre o desempenho das atividades realizadas no canteiro de obras, impedindo que a produtividade melhore sem informações corretas e significativas; e (3) redução ao máximo das atividades que não agregam valor, mas existem durante o processo construtivo, como os acidentes ou defeitos de estruturas.

Apesar de buscar a eliminação de todas estas atividades que não geram valor para o cliente final, deve se analisar que algumas dessas atividades podem gerar valor interno durante a produção, como auxiliar no planejamento ou prevenção de acidentes, sendo benéficas no processo global.

b) Redução do tempo de ciclo: O tempo de ciclo dentro do sistema de produção considera o tempo de processamento, tempo para inspeções, tempo de espera e tempo para movimentações necessárias. Um dos princípios de Koskela (1992) visa a diminuição deste tempo, pois segundo o autor o tempo é uma métrica mais útil e universal do que tempo e qualidade, e sua redução pode melhorar estes outros dois parâmetros.

A premissa atrás deste princípio é que ao reduzir este tempo ciclo, são forçadas as eliminações de desperdícios durante a inspeção, movimentação e espera. Além disso, esta redução do tempo de ciclo pode trazer benefícios para o cliente final como: entrega mais rápida ao consumidor, redução da necessidade de previsões sobre demandas futuras, redução das problemas durante o processo de produção devido a mudanças de pedidos e maior facilidade no gerenciamento da produção por ter menos pedidos ao mesmo tempo.

c) Redução da variabilidade: Durante o processo de produção existem muitos tipos de variabilidades que podem o influenciar, como diferenciação dimensional de materiais ou matérias-primas, variação durante a execução de uma atividade, entre outros (SCHEER et al., 2008).

Segundo Koskela (1992) existem dois principais motivos para a busca da redução da variabilidade durante o processo construtivo: (1) No ponto de vista do consumidor é melhor que o produto seja uniforme; e (2) a variabilidade durante a produção pode aumentar o volume de atividades que não agregam valor ao produto, além de aumentar o tempo de ciclo de produção.

A partir destes problemas trazidos pela variabilidade durante o processo de produção, Koskela (1992) afirma a necessidade de buscar sua redução dentro dos canteiros de obras, através principalmente da uniformização das atividades e procedimentos durante a construção e uso de práticas estatísticas que reduzam variabilidades, como instrumentos de identificação de defeitos, como o "*poka-yoke*".

d) Simplificação por meio da minimização do número de passos, partes e dependências: Dentro do processo de produção um número elevado de passos ou partes pode contribuir para que existam mais atividades que não agreguem valor ao produto, pois mais atividades auxiliares podem ser necessárias para atender todas as etapas deste processo (SCHEER et al., 2008). Além disso, quanto maior a quantidade de partes, maior será a complexidade do processo, algo que pode facilmente ultrapassar a capacidade humana para lidar com essa complexidade (KOSKELA, 1992).

Para atingir uma Construção Enxuta, Koskela (1992) sugere que um dos seus princípios deva ser de redução das etapas durante o processo produtivo. Este princípio pode ser atingido ao reduzir-se o número de componentes dentro do produto final ou reduzir-se a quantidade de etapas dentro do fluxo dos materiais ou da informação.

Dentro das atividades práticas nesta busca de redução de etapas, podem ser realizados o encurtamento de fluxos ao consolidar-se as atividades, redução de partes do produto ao modificar sua concepção, uniformizar partes ou materiais, minimizar a quantidade de informação requerida para o controle, entre outras (KOSKELA, 1992).

e) Aumento da flexibilidade na execução do produto: A ideia atrás do princípio de aumentar a flexibilidade do produto é oferecer ao cliente final um produto com maiores possibilidades de customizações sem que o custo de produção aumente muito, mesmo que seja algo contraditório ao princípio de simplificação das etapas (KOSKELA, 1992).

Para atingir um aumento na flexibilidade sem que o processo de produção se torne mais complexo, podem ser reduzidos os tamanhos de lotes se aproximando da demanda, deixar o processo de customização do produto nas fases finais da produção e manter uma equipe treinada para realizar diferentes tarefas e atividades de acordo com o requerimento do cliente (KOSKELA, 1992).

f) Aumento na transparência do processo: A falta de transparência no processo de produção pode aumentar a possibilidade da ocorrência de erros, ao mesmo tempo que ajuda a mascará-los. Além disso, ela pode aumentar a quantidade de atividades que não agregam valor ao produto, como esperas e movimentações (SCHEER et al., 2008).

Diante disso, Koskela (1992) propõe que a Construção Enxuta busque um aumento de transparência durante todas etapas da produção, para que o fluxo de operações e atividades seja claramente visível e compreensível para todos os trabalhadores.

Este aumento na transparência da produção pode ser atingido ao transformar o processo mais facilmente observável com mudanças de fluxos e do leiaute da produção, fazer com que atributos normalmente invisíveis do processo se tornem visíveis através de medições e ferramentas, inserir informações em todas áreas de trabalho, uso de ferramentas visuais para que os trabalhadores identifiquem padrões do processo mais facilmente, reduzir a interdependência entre unidades de produções, entre outras atividades (KOSKELA, 1992).

g) Melhorar o valor do produto através de considerações sistemáticas dos requisitos do cliente: Dentro do processo de produção existem dois tipos de clientes que devem ser considerados: os clientes internos, que são os trabalhadores que estão na etapa seguinte da produção, e os clientes finais, que irão consumir o produto (KOSKELA, 1992).

Para que se atinja um maior valor do produto em referência ao cliente, seja ele interno ou final, devem ser sempre levados em consideração os seus requisitos, sendo questionados, analisados e implantados assim que possível, para que possa ser garantida a satisfação pelo produto final (SCHEER et al., 2008)

h) Focar o controle no processo global: Durante a otimização de subprocessos dentro de uma cadeia de produção, existe o risco de ser dado grande enfoque em uma das atividades e acabar melhorando esta atividade, porém impactando negativamente o desempenho global da produção (ISATTO et al., 2000).

Para que esta situação não ocorra, Koskela (1992) cita que o foco no controle da produção deva ser no processo global. Quando isso é feito, a identificação de possíveis problemas e defeitos durante a produção, que possam vir a interferir no prazo de entrega da obra, ocorre mais facilmente (BERNARDES, 2003).

i) Introduzir a melhoria contínua do processo: A introdução dos princípios descritos por Koskela (1992) dentro da construção civil pode ser uma tarefa complexa, portanto buscar uma melhoria constante e contínua durante a produção é a chave para atingir o sucesso da Construção Enxuta (SCHEER et al., 2008).

Essa melhoria contínua pode ser atingida através da medição e monitoramento dos processos, definição de metas para a produção, dar responsabilidade de melhoria individual para cada trabalhador, utilizar procedimentos padrões como melhores práticas que possam sempre ser melhoradas, entre outras atividades (KOSKELA, 1992).

j) Balancear as melhorias no fluxo com as melhorias nas conversões: Como citado anteriormente, o modelo atual de conversão da construção civil desconsidera os fluxos do processo, portanto melhorias no fluxo têm o potencial de trazer grandes benefícios para as construções, pois de acordo com Koskela (1992) quanto maior a complexidade do processo produtivo, maior o impacto de melhorias em seu fluxo.

Apesar disso, deve-se buscar um balanceamento entre as melhorias de fluxo com as melhorias de conversões, pois normalmente as melhorias de fluxo têm um menor investimento inicial, mas demandam mais tempo para implementação do que as melhorias de conversões (KOSKELA, 1992).

Ainda assim Ohno (1997) acredita que muitas vezes é mais benéfico para a empresa a busca por melhorias de fluxo na produção antes de se realizar maiores investimentos em novas tecnologias de conversão, para que todo o seu potencial seja atingido com as melhorias de fluxos e então seja possível o investimento nas novas tecnologias de conversão.

k) Referências de ponta (*Benchmark*): Apesar da Indústria da Construção Civil ter o seu próprio processo produtivo e as atividades de conversões específicas para a sua área, os processos de fluxos são muito próximos ou parecidos de outras áreas, portanto se torna imprescindível a identificação de casos e práticas bem sucedidos que possam ser aproveitados dentro da construção civil (KOSKELA, 1992).

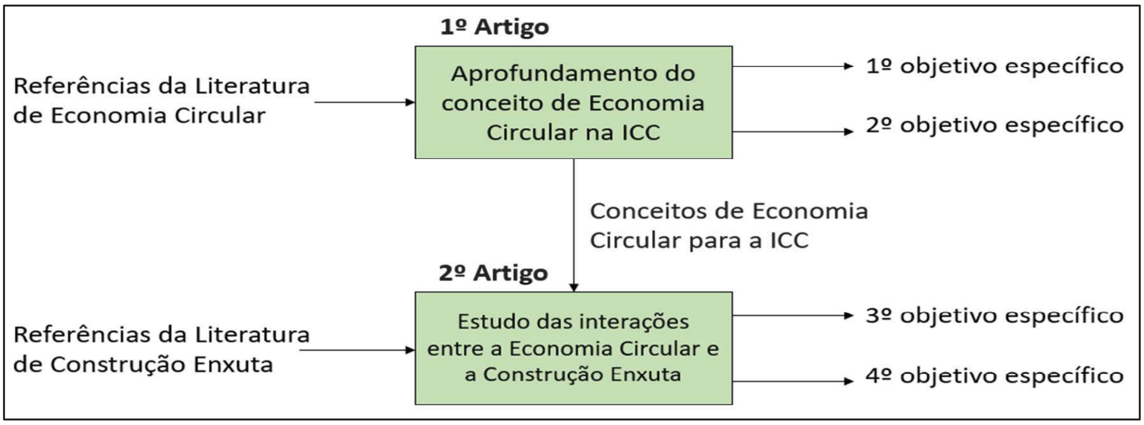
Finaliza-se este resgate teórico e parte-se para a apresentação do encaminhamento metodológico e a discussão dos conceitos aprofundados nesta seção de referencial teórico.

3 ENCHAMINHAMENTO METODOLÓGICO

Esta pesquisa é bibliográfica com técnica de revisão sistêmica e análise de conteúdo. A estrutura de apresentação do texto foi dividida em dois artigos, com o primeiro sendo responsável por trazer os desenvolvimentos recentes da Economia Circular dentro da construção civil e identificar suas práticas existentes. Já o segundo artigo parte-se para a criação de uma matriz de correlações entre as práticas da EC encontradas no primeiro artigo e os princípios da Construção Enxuta definidos por Koskela (1992).

Este capítulo irá trazer de forma abreviada os métodos utilizados para cada um dos artigos, uma vez que dentro de cada artigo estes métodos estão mais bem explicados e detalhados. Além disso, a FIGURA 8 traz de forma abreviada como os conceitos abordados na seção anterior estão inseridos nessa dissertação.

FIGURA 8 - CONEXÃO DOS CONCEITOS TRATADOS NO REFERENCIAL TEÓRICO



FONTE: O autor (2020).

3.1 PRIMEIRO ARTIGO – ECONOMIA CIRCULAR DENTRO DA INDÚSTRIA DA CONSTRUÇÃO CIVIL: UMA REVISÃO SISTEMÁTICA DA LITERATURA

A primeira etapa desta pesquisa busca-se por atingir os dois primeiros objetivos específicos definidos, encontrar os desenvolvimentos recentes de pesquisas dentro do tema de Economia Circular para a construção civil, e criar uma lista de práticas existentes dentro deste conceito para o ambiente construído.

Para atingir estes objetivos específicos, realizou-se uma Revisão Sistemática da Literatura. Este método fornece um resumo dos estudos realizados dentro da área, além de encontrar as lacunas de conhecimento ainda não exploradas pelas pesquisas (WEBSTER; WATSON, 2002).

O método escolhido para esta revisão segue o protocolo de Briner e Denyer (2012), pois, segundo os autores, é focado em incorporar o problema da pesquisa e garante que a revisão é sistemática, transparente e replicável. Esse método divide uma revisão sistemática da literatura em oito passos: (1) revisão inicial; (2) definição do objetivo; (3) critério para inclusão de artigos; (4) estratégia para obtenção dos artigos; (5) elegibilidade; (6) coleta de dados; (7) método para garantia da qualidade; e (8) resumo dos resultados. A definição destes passos para esta pesquisa está descrita no QUADRO 2.

QUADRO 2 - PROCEDIMENTO PARA REVISÃO DA LITERATURA

Etapas	Pesquisa
Revisão inicial	Como os conceitos da Economia Circular podem ser utilizados na ICC
Objetivos	Encontrar os desenvolvimentos recentes da Economia Circular dentro da construção civil
Critério para inclusão de artigos	Artigos que utilizaram conceitos da EC no setor da construção através de uma rede bibliométrica
Estratégia para obtenção dos artigos	Pesquisa dentro de 3 bases de dados (*Science Direct, Web of Science* e *Scopus*) por artigos publicados nos últimos 5 anos
Elegibilidade	Artigos revisados por pares ou de conferências
Coleta de dados	Exclusão de artigos repetidos; leitura do *abstract*; leitura do artigo completo; adição de artigos importantes que não foram incluídos pelo processo
Verificação da qualidade	Artigos analisados pelos autores
Resumo dos resultados	Resumos e resultados dos artigos divididos entre áreas de pesquisa

Fonte: O autor (2020).

Os resultados obtidos foram divididos em duas partes. Primeiramente com os resultados descritivos dos dados bibliométricos dos 45 artigos incluídos nesta revisão da literatura, e na sequência os resultados sobre o conteúdo de todos artigos.

Dentro dos resultados do conteúdo dos artigos envolvidos nesta revisão da literatura, foram analisadas as definições mais citadas para o conceito de

Economia Circular. As etapas do ciclo de vida das edificações mais abordadas nas pesquisas foram investigadas, como também foram divididos os artigos em seis linhas de pesquisa diferentes. Por fim, foi criada uma lista de atividades e práticas da construção civil que utilizam os conceitos da Economia Circular, dívidas entre as diferentes fases do ciclo de vida de uma edificação.

Na sequência tem-se as discussões sobre os resultados obtidos e identificadas as lacunas de pesquisa dentro deste tema.

3.2 SEGUNDO ARTIGO – INTERAÇÕES ENTRE OS PRINCÍPIOS DA CONSTRUÇÃO ENXUTA E AS PRÁTICAS DA ECONOMICA CIRCULAR PARA A CONSTRUÇÃO CIVIL

A segunda etapa desta pesquisa foi responsável por atingir os dois últimos objetivos específicos definidos para esta dissertação. Primeiramente, relacionar as práticas da Economia Circular dentro da ICC encontradas no primeiro artigo com os princípios da Construção Enxuta definidos por Koskela (1992). Na sequência, identificar uma sequência de práticas da Economia Circular utilizadas no ciclo de vida de uma edificação, que mais se assemelhem aos princípios da Construção Enxuta.

Para atingir os objetivos definidos, foi definido o método de pesquisa como Análise de Conteúdo de Bardin (1977), que tem o objetivo de obter índices (quantitativos ou não), através de procedimentos sistemáticos e objetivos, que permitam a inferência de conhecimento do conteúdo analisado (BARDIN, 1977).

Este método segue um protocolo dividido em três grandes partes: (1) pré-análise; (2) exploração do material; e (3) tratamento dos resultados e interpretação.

Na etapa de pré-análise, é realizada uma leitura flutuante, responsável pelo primeiro contato e familiarização com o tema, seguido pela escolha do material que será incluído na pesquisa. Na sequência, as hipóteses e objetivos são definidos, e então o material pode ser preparado para ser analisado.

Na fase de análise do conteúdo é escolhida uma técnica que melhor se encaixa na busca dos objetivos traçados. Para esta pesquisa foi escolhido utilizar a técnica de análise de relações, possibilitando a criação de uma matriz que correlacionasse as práticas de Economia Circular para a ICC e os princípios da Construção Enxuta.

A fase seguinte, e final, da análise de conteúdo de Bardin (1977) é o tratamento dos resultados obtidos e interpretações possíveis. Nesta etapa ocorrem as operações estatísticas dos resultados obtidos, para facilitar sua compreensão, seguido de uma síntese dos resultados, e por fim as inferências e conclusões possíveis através dos resultados obtidos. O QUADRO 3 mostra os passos seguidos para esta pesquisa.

QUADRO 3 - SEQUÊNCIA DE ETAPAS SEGUIDAS DENTRO DESTA PESQUISA

Etapas	Estratégia adotada
Pré-análise	
Leitura flutuante	Leitura do material dentro dos tópicos de Economia Circular, produção enxuta, pensamento enxuto e Construção Enxuta
Escolha de documentos	Foco em artigos revisados por pares ou de conferências que focam nos temas de Economia Circular para a ICC e Construção Enxuta
Definição de hipóteses e objetivos	Encontrar a correlação entre as práticas da Economia Circular para a ICC e os princípios da Construção Enxuta
Preparação do material	Uso da tabela encontrada no primeiro artigo com as práticas da EC e os princípios da CE definidos por Koskela (1992)
Exploração do material	
Uso de técnicas para a Análise de Conteúdo	Criação de uma matriz de relações entre as práticas da EC e os princípios da CE, baseado na análise de relações de Bardin (1977)
Tratamento dos resultados e interpretações	
Operações estatísticas	Uso do software Excel para compilar os resultados estatísticos
Síntese dos resultados	Lista de todas as relações encontradas entre as práticas da EC e os princípios da CE, com explicações
Inferências	Discussão dos resultados obtidos
Interpretações	Conclusões possíveis a partir dos resultados obtidos e suas discussões

FONTE: O autor (2020).

Dentro deste estudo foi possível encontrar uma lista de 74 interações, 70 positivas e 4 negativas, sendo analisadas as práticas e princípios que mais tiveram interações entre si e as etapas do ciclo de vida da edificação com mais interações com os princípios da CE. Por fim, foi desenvolvido uma sequência de práticas da Economia Circular dentro do ciclo de vida da edificação que obtiveram mais similaridades com os princípios da Construção Enxuta.

4 CIRCULAR ECONOMY IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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Abstract: The Construction Industry is responsible for over 30% of the extraction of natural resources, as well as 25% of solid waste generated in the world. This happens because the construction sector mostly adopts a linear economic model of "take, make, dispose", using materials to the construction of buildings and disposing them at the end of life, since they are assembled for one time use and don't retain potential for reuse. Over the last decades, a paradigm shift has been occurring in the industry at large, with the adoption of a Circular Economy model, that aims at keeping the materials in a closed loop to retain their maximum value, therefore with a greater potential of reducing the waste generation and resources extraction for the Construction Industry. This article aims at finding the recent developments of how Circular Economy can be used inside the construction industry. To achieve this goal, a systematic literature review was conducted, including 45 articles that were divided into six areas of research: development of Circular Economy, reuse of materials, material stocks, Circular Economy in the built environment, LCA analysis and material passport. An analysis of the content of these articles was made and the knowledge gaps in this area were identified, as well as table with known Circular Economy practices for the Construction Industry was created divided by life cycle stages. Finally, a discussion of each area of research and their findings is made.

Keywords: Circular Economy; Construction Industry; Built environment; Literature review.

4.1 INTRODUCTION

Over the last three decades, it has been known that the Construction Industry consumes a huge amount of natural resources, as it was responsible for over 40% in the 1990s (REES, 1999) and nowadays this number only falls to around 32% (YEHEYIS et al., 2013). Not only consuming, the Construction Industry is also responsible for one quarter of the solid waste (YEHEYIS et al., 2013) generated worldwide, and it can reach bigger numbers in countries under development like Brazil, where waste generated by the Construction Industry reaches over 60% (ABRELPE, 2018).

The waste generated by construction and demolition (C&D) happens throughout the life cycle of buildings, even through planning and design phases since there is a lack of consideration on waste management and waste reduction in earlier phases of a project (ESA; HALOG; RIGAMONTI, 2016). However, the most impactful phase in terms of C&D waste generation is the end of life, which accounts for 50% of the numbers (KIBERT, 2008), which happens because most of building materials are often disposed at their end of life, since they don't have a potential for reuse (AKANBI; OYEDELE; AKINADE, 2018).

This problem mainly happens because the Construction Industry uses a linear economic model, based on the idea of "take, make, dispose of" (EMF, 2015). In this model, the phases that feature this idea start with the extraction of raw materials from the environment, that are then processed into becoming construction materials and assembled in the construction site, in ways that cannot be deconstructed, becoming obsolete at the end of life of the building, having to be disposed in landfills or incinerated, along with all the waste generated through the whole process (MANGIALARDO; MICELLI, 2018).

In contrast, another economic model that has been gaining attention in the last decades is the Circular Economy, that has its founding principals in better management of resources (POMPONI; MONCASTER, 2017). Through a series of reports, Ellen MacArthur Foundation has been promoting the ideas and opportunities of Circular Economy, defining it as a regenerative system that aims to keep materials in a closed loop at their highest value (EMF, 2015).

In the Circular Economy models, the end of life building materials should be reused and their components and parts deconstructed, to act as material banks for new buildings, keeping the components and materials in a closed loop (HOPKINSON et al., 2019), just as EMF proposes in the general Circular Economy concept. However, this idea still needs development of knowledge and tools to have a larger adoption in the industry (LACY; RUTQVIST, 2015), especially in the Construction Industry, where innovation takes more time to be implemented (BIS, 2013), since buildings are most of the time unique projects with a large supply chain that only adds to the complexity involved (POMPONI; MONCASTER, 2017).

Therefore, this article aims at finding the recent developments of how Circular Economy concepts can be used inside the Construction Industry, using a systematic literature review of existing databases. This paper is organized as follows. Section 2 explains the methods that were used, Section 3 shows the results of this literature review, Section 4 brings a discussion about the bibliometric and content results, as well as the knowledge gaps in this field, and Section 5 ends the articles with a conclusion of this literature review.

4.2 SYSTEMATIC REVIEW METHODOLOGY

The chosen method for this research was a systematic review, as it is an essential feature on any research activity (ESA; HALOG; RIGAMONTI, 2016), since it provides a summary of previous studies in the area and looks for the gaps of knowledge in those published studies (WEBSTER; WATSON, 2002). According to Briner and Denyer (2012) this method should follow these principles: (1) review conducted systematically or through a method; (2) present a transparent method; (3) be replicable and updatable; (4) summarize and synthetize the main subject of the research. Table 1 shows how those steps were utilized in this research.

TABLE 1 - STEPS OF THE SYSTEMATIC REVIEW

Steps	Research
Initial review	How Circular Economy concepts can be used in the Construction Industry
Objective	Find recent developments of CE in the Construction Industry
Criteria for considering studies	Papers that used concepts of CE in the Construction Industry through a bibliometric network
Strategy to obtain the studies	Research inside three databases (Science Direct, Web of Science and Scopus) for articles published in the last 5 years
Eligibility	Peer reviewed and proceedings
Data collection	Exclusion of repeated articles; read of abstracts; read of full articles; addition of relevant articles that were not included in this process
Quality assessment	Articles analyzed by the authors
Synthetize results	Summary and results of all analyzed papers divided by area of research

SOURCE: The authors (2020).

Tranfield, Denyer and Smart (2003) defined three stages for conducting a systematic review, with the first stage about planning the review, followed by the conduction of the review and finally, the last stage is reporting and dissemination of the results. Later, Briner and Denyer (2012) developed a protocol to conduct a systematic review, adapting from Higgins and Green (2008), incorporating those stages in eight steps: (1) initial review, that defines the problem that will be studied; (2) definition of the objective; (3) criteria from considering studies, that defines the types of researches that will be included in the review; (4) strategy to obtain the studies, according to which databases will be selected; (5) eligibility, that eliminates those studies that do not meet the pre-established criteria; (6) data collection, the manner in which the data will be obtained; (7) quality assessment method, that evaluates the quality of the collected data; (8) synthetize the results.

This protocol was followed for the conduction of this review, since it is focused on incorporating the research question and ensures that this review is systematic, transparent and replicable (BRINER; DENYER, 2012).

4.2.1 Steps of the systematic review

The first step of this literature review was to define the problem that would be studied, that is "How can the concept of Circular Economy be utilized in the Construction Industry to help minimize waste generation?". The objective of the review was defined as to identify the recent developments of Circular Economy in the building sector and how are they being used. The following step was the definition that the studies that would be included in this review were those that used concepts of Circular Economy in a research within the Construction Industry. Additionally, this definition included the creation of a bibliometric network of all the abstracts of a preliminary research, to find the most relevant subjects within those papers, that would the focus of this research.

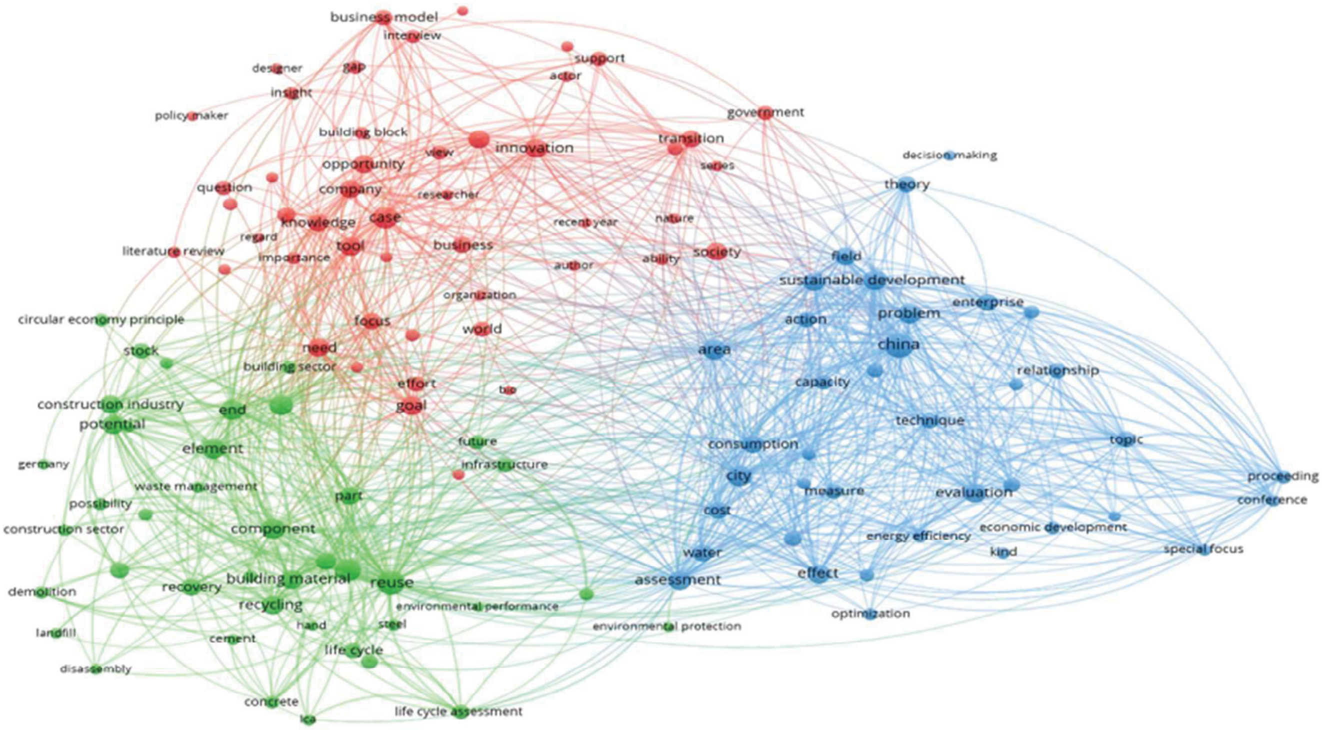
The strategy to obtain the articles started with preliminary research to create a bibliometric network of the words used in the abstracts. A bibliometric network consists of nodes and edges that indicates the correlation between the words, and the strength of the connection through the edges (VAN ECK; WALTMAN, 2014). The objective in creating this network for this review was to delimitate the biggest areas of research inside the theme of Circular Economy for the Construction Industry and then focus the review on those areas.

To help create and visualize this bibliometric network, the software VOS Viewer was used to create a distance-based network, in which the distance between two nodes indicates their correlation and the bigger the node, the bigger the number of citations the word has (VAN ECK; WALTMAN, 2014).

This software delimits the use of only one database for network, therefore this preliminary research was conducted in the three databases used in this review (Science Direct, Web of Science and Scopus), and the database that found the biggest number of results was used to create this network. In this preliminary search it was used the words “Circular Economy” and “Buildings”, that found 375 results in the Scopus database (Science Direct and Web of Science had 115 and 70, respectively), therefore it was the used database.

FIGURE 1 shows the results of this bibliometric network, clearly dividing the most used words in three areas of focus.

FIGURE 1 - BIBLIOMETRIC NETWORK OF “CIRCULAR ECONOMY” AND “BUILDINGS”



SOURCE: The authors (2020).

This division shows that there were three most researched different areas of research inside this theme. The three chosen words to focus this systematic review were “reuse”, “case” and “technique”, with the last one not being the most common in its area, however it was used instead of “China” since it would most likely restrict studies to that country.

With the definition of the words of focus for this study, the initial search was conducted in the three databases using the combination of: “Circular Economy” AND “Buildings” AND (“Reuse” OR “Technique” OR “Case”). This first search found 262 total papers. Then all the papers that were not peer reviewed or proceedings, as well of not being published in the last five years were eliminated, resulting in 214.

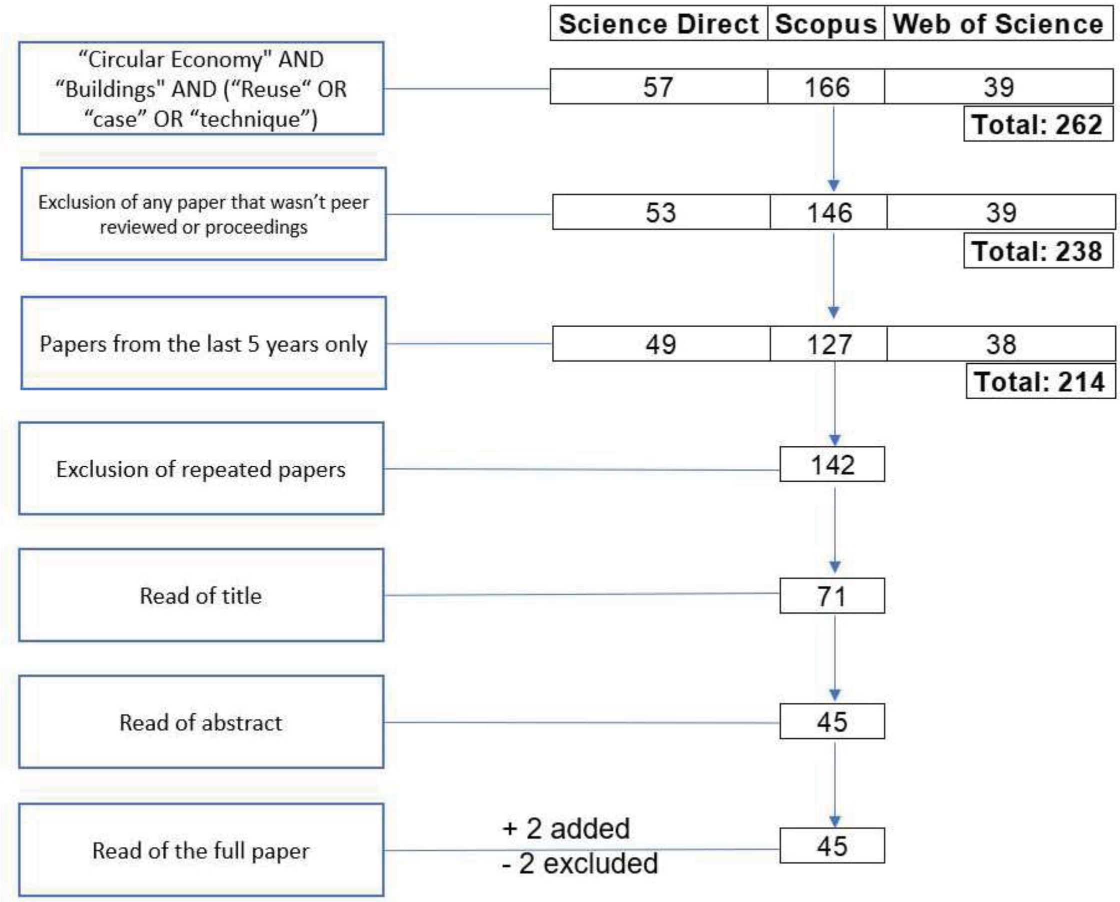
The next step of eliminating the repeated articles, reached 142 results. To eliminate most of the papers that were not related to the Construction Industry, a read of all the titles was made, reducing the total to 71 papers. This drastic reduction by only reading the title can be explained since the word “buildings” can mean the creation of something, therefore the article could have the searched keywords but be in a totally different field than the Construction Industry.

The first analysis of content was conducted by reading the abstract of the remaining articles and eliminating all that was not relevant for the use of Circular Economy in the Construction Industry, resulting in 45 articles. The last step was a reading of the complete papers, excluding those that didn’t meet the established criteria and inserting relevant papers that were not included in the search of the databases. This last step eliminated 2 articles and included 2 more, resulting in a final number of 45 articles that were used in this literature review. FIGURE 2 summarizes this process.

The second to last step of this protocol was the quality assessment of these articles, that considered the integrity of all the databases used and the fact that all the papers were peer reviewed or proceedings, ensuring they were reliable sources for this review.

Additionally, a bibliometric analysis about the 45 articles was made, with the help of the software Excel, and reported the results in the next section. Finally, this systematic review was concluded with a content analysis, in which the definition of Circular Economy given in each paper was collected, the life cycle stages contemplated in each article was analyzed and a summary of all the articles included in this literature review was given, with their respective findings.

FIGURE 2 - ARTICLE SELECTION SEQUENCE



SOURCE: The authors (2020).

After the found results, the next section will bring the discussion about the descriptive and content results, respectively.

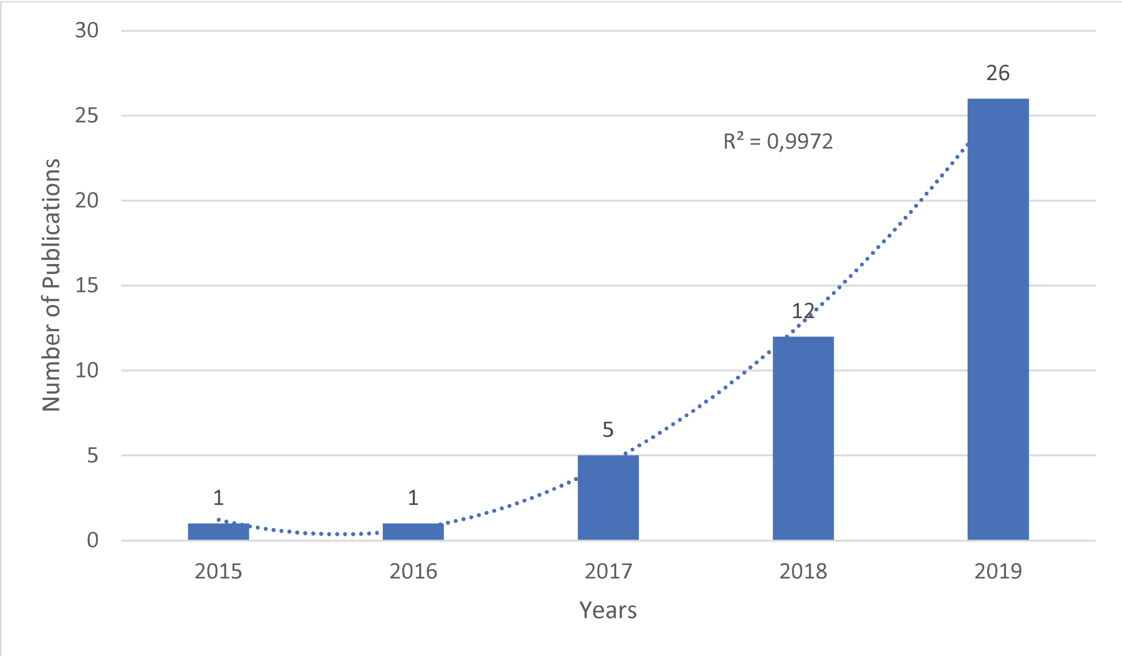
4.3 RESULTS

The results of this research are divided into two parts, first it will be provided a descriptive analysis of the bibliometric results obtained, followed by an analysis of the content of the articles included in this literature review. The articles were divided into six different research themes and each paper was given a brief summary.

4.3.1 Descriptive analysis

The first bibliometric analysis is about the number of publications per year, as shown in FIGURE 3.

FIGURE 3 - NUMBER OF PUBLICATIONS PER YEAR



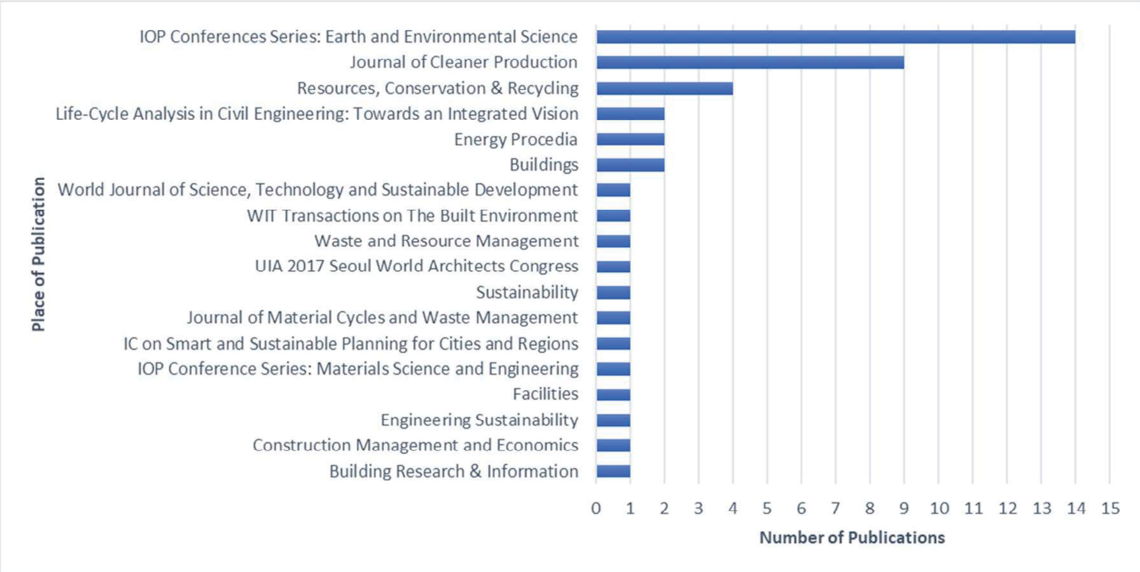
SOURCE: The authors (2020).

There is definitive increase in the number of articles published since 2017, as the number grew exponentially, and it shows a clear indicative that this topic of research is starting to gain traction in the built environment and will likely continue to grow in terms of number of publications. Also, this literature review only covers papers that were published until May of 2019, so the number for this year will likely be even higher than already is.

Another analysis made was about the place of publication of the papers, that might help understand the big increase that 2019 has shown in number of publications, although this research did not include half of the year. FIGURE 4 shows that the biggest place of publication was the conference proceedings “IOP Conference Series: Earth and Environmental Sciences”, with 14 papers, that in this special case was the proceedings of the event named “Building as Material

Banks – A pathway for a circular future", that had the theme of Circular Economy in the built environment and happened in the beginning of 2019.

FIGURE 4 – PLACES OF PUBLICATIONS

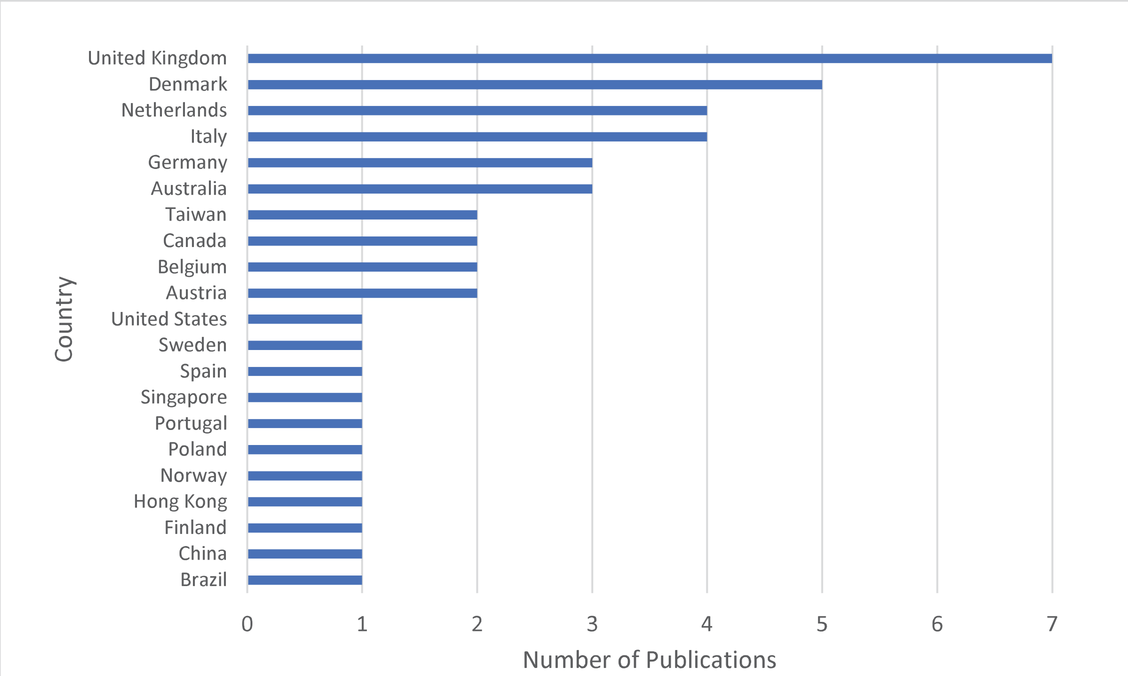


SOURCE: The authors (2020).

The next biggest sources of publications were "Journal of Cleaner Production" and "Resources, Conservation and Recycling", with 9 and 4 publications respectively, both journals with qualification "Q1" in the Scimago Journal & Country Rank (SJR) showing the interest of important research sources.

Finally, an analysis about the country that had most publications was conducted, as the results as shown in FIGURE 5. The country with the greatest number of papers in this review was the United Kingdom, with seven, followed by Denmark with five, Netherlands and Italy, four each. Also, Europe was by far the continent with the most publications in this area, with 34 of the 45 papers included in this review. The next continent was Asia with only 4 publications.

FIGURE 5 – COUNTRIES OF PUBLICATIONS



SOURCE: The authors (2020).

4.3.2 Content analysis

The content analysis of this research is divided into four stages: (1) Definition of Circular Economy for the built environment; (2) Stages of the life cycle included in the researches; (3) Analysis by research theme; and (4) List of Circular Economy practices by life cycle stage.

4.3.2.1 Definition of Circular Economy for the built environment

A first analysis about the content of the articles was made regarding the definition that was used for Circular Economy for the Construction Industry. This analysis was made by selecting all the sources of definitions of "Circular Economy" in the articles included in this literature review, weather it was defined in regards of the built environment or for the general industry, and in the end a definition of Circular Economy for the Construction Industry is given by the authors.

The most cited source of definition about this concept was Ellen MacArthur Foundation, with 12 citations of their several reports (EMF, 2012, 2013, 2014,

2015) that has helped increasing the awareness in this subject, as they have published multiple reports promoting the opportunities of adoption of Circular Economy in our society. They have defined Circular Economy as “restorative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles” (EMF, 2015).

Two other sources have been cited multiple times in this review. First, Lacy and Rutqvist (2015), cited 4 times, have a bigger focus on the competitive advantage that companies can acquire through the Circular Economy, as they call “circular advantage”. They define Circular Economy as the opposite of the usual consumption of natural resources, as the “circular approach keep resources in productive use in the economy for as long as possible” (LACY; RUTQVIST, 2015).

The other common cited source was Pomponi and Moncaster (2017), with 4 citations, that, unlike the other authors, had their focus on the definition of Circular Economy for the Construction Industry. They conducted a literature review on the existing general Circular Economy definitions, in which they found six different dimensions that CE must be addressed in the built environment: governmental, economic, environmental, behavioural, societal and technological. In their definition, they considered Circular Economy for the Construction Industry as a “building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles” (POMPONI; MONCASTER, 2017).

Outside of the most cited sources, there has also been some authors that had only one citation as source of definition for the concept but with the focus on the Construction Industry, as Geissdoerfer et al. (2017) defined a “regenerative closed loop system which can be achieved through appropriate design, maintenance, refurbishing or reuse”. Later, Leising, Quist and Bocken (2018) defined the Circular Economy approach for buildings as a “life cycle approach that optimizes the buildings’ useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank”.

We have considered the definitions given by the Circular Economy of the most cited sources in a general manner, and most of them have the focus on the general concept of Circular Economy and only a few focus on the Construction Industry, with only one (LEISING; QUIST; BOCKEN, 2018) considering the life cycle of a building in the definition. Therefore we found the necessity to define the concept of Circular Economy focused on the Construction Industry, as well as considering the life cycle stages of a building, as “the use of practices, in all stages of the life cycle of a building, to keep the materials as long as possible in a closed loop, to reduce the use of new natural resources in a construction project”.

4.3.2.2 Stages of the life cycle included in the researches

A second analysis about the content of the included papers in this review was conducted in terms of which life cycle stages of a building were contemplated in these researches. The considered stages were project design, material manufacture, construction, operation and end of life.

The consideration of these five phases takes into account the European standard EN 15978:2011, that specifies the calculation method for Life Cycle Assessment (LCA) of a building and considers four main life cycle stages: (1) product manufacture; (2) construction; (3) operation; and (4) end-of-life. It also considers the definition from the EU funded Building As Material Banks (BAMB) project that defines also four main life cycle stages, however it does not consider the product manufacture phase, but it does consider the project design phase as the initial phase (BAMB, 2016).

The combination of both definitions has been used by Adams et al. (2017) and it has been chosen for this research, since multiple practices based on the concept of Circular Economy must happen in the design phase of a project as well as in the manufacture of the building parts and structures, therefore it will help the differentiation of stages for this research.

TABLE 2 shows that the end of life of buildings was the stage that most appeared in the articles, with two thirds of them (30) considering, followed by the project design, with 14. The phase that was least covered was the operation, with only 4 papers discussing it. Also, out of all the articles, the most common approach was to consider only one of the stages, used by 21 papers, followed by considering 2 stages (15). In this review only one article (HOSSAIN; NG, 2018) considered all five stages in its research.

TABLE 2 – LIFE CYCLE STAGES OF THE BUILDING CONSIDERED IN THE PAPERS

Article	**Building life cycle stages**					Totals
	Project Design	**Manufacture**	**Construction**	**Operation**	**End of life**	
Smol et al. (2015)		X			X	2
Geldermans (2016)		X	X		X	3
Adams et al. (2017)	X				X	2
Oezdemir; Krause; Hafner (2017)		X			X	2
Esa, Halog and Rigamonti (2016)					X	1
Pomponi and Moncaster (2017)	X		X		X	3
Swift et al. (2017)	X	X			X	3
Sanchez and Haas (2018a)					X	1
Tallini and Cedola (2018)		X	X			2
Sanchez and Haas (2018b)	X					1
Sauter, Leemens and Pauwels (2018)	X					1
Leising, Quist and Bocken (2018)	X	X	X		X	4
Huang et al. (2018)					X	1
Hossain and Ng (2018)	X	X	X	X	X	5
Ghisellini, Ripa and Ulgiati (2018)					X	1
Mangialardo and Micelli (2018)	X		X		X	3
Akanbi, Oyedele and Akinade (2018)	X				X	2
Minunno et al. (2018)	X	X				2
Nuñez-Cacho et al. (2018)	X		X	X	X	4

Chang and Hsieh (2019)	X					1
Nordby (2019)					X	1
Maerckx et al. (2019)	X		X		X	3
Heinrich and Lang (2019)		X			X	2
van Bueren, Leenders and Nordling (2019)			X			1
Nußholz, Nygaard and Milios (2019)		X			X	2
Manelius, Nielsen and Kauschen (2019)			X		X	2
Eberhardt, Birgisdóttir and Birkved (2019a)		X			X	2
Nijgh and Veljkovic (2019)		X				1
Akanbi, Oyedele and Akinade (2019)	X				X	2
Kyrö, Jylhä and Peltokorpi (2019)	X				X	2
Gepts et al. (2019)					X	1
Honic, Kovacic and Rechberger (2019)	X					1
Bertino et al. (2019)				X		1
Eberhardt, Birgisdottir and Birkved (2019b)	X					1
Ali (2019)	X					1
Eberhardt, Birgisdottir and Birkved (2019c)	X		X		X	3
Munaro et al. (2019)	X					1
Ajayabi et al. (2019)		X			X	2
Hopkinson et al. (2019)		X			X	2
Krause and Hafner (2019)	X				X	2
Arora et al. (2019)					X	1
Akanbi, Oyedele and Delgado (2019)					X	1

Pimentel-Rodrigues and Siva-Afonso (2019)				X		1
Rasmussen, Birkved and Birgisdóttir (2019)	X					1
Ünal et al. (2019)	X					1
Totals	23	14	11	4	30	

SOURCE: The authors (2020).

The fact that only one article considered all stages, and most considered only shows that the research in this area is still focused on applying the concepts of Circular Economy in the build environment in only one life cycle stage at a time. This means that research is still trying to understand how to use Circular Economy practices in specific cases for construction, and not yet focusing in a more global use of those concepts, which can be understood as a challenge for future researches in this area to incorporate Circular Economy in more life cycle stages of a building.

4.3.2.3 Analysis by research theme

The content analysis of each articles was divided by six different research areas that were found in this review. This division was made in regard of the main area that each research followed; however, they were not always the focus of their researches. Therefore, this division was made to facilitate the understanding of recent developments of articles in similar areas of research inside the main theme of Circular Economy in the Construction Industry.

TABLE 3 shows each article that was included in this literature review and the research theme that it was considered. The summary of each article is given in the APPENDIX 1, in chronological order of publication, separated by each area of research. At APPENDIX 2, the most important results and findings of each article are given, as well as their contributions, by area of research. In the discussion section of this article, an explanation of each area of research is shown, with the recent developments of their researches.

TABLE 3 – ARTICLES IN THIS LITERATURE REVIEW BY AREA OF RESEARCH

Nº of Articles	Area of research	Authors
13	Development of Circular Economy in the built environment	Adams et al. (2017); Pomponi and Moncaster (2017); Esa, Halog and Rigamonti (2016); Leising, Quist and Bocken (2018); Huang et al. (2018); Mangialardo and Micelli (2018); Nuñez-Cacho et al. (2018); Minunno et al. (2018); Chang and Hsieh (2019); Maerckx et al. (2019); van Bueren, Leenders and Nordling (2019); Ünal et al. (2019); Eberhardt, Birgisdottir and Birkved (2019c)
12	Reuse of materials	Smol et al. (2015); Geldermans (2016); Sanchez and Haas (2018); Tallini and Cedola (2018); Ghisellini, Ripa and Ulgiati (2018); Nordby (2019); Nußholz, Nygaard and Milios (2019); Manelius, Nielsen and Kauschen (2019); Nijgh and Veljkovic (2019); Akanbi, Oyedele and Delgado (2019); Pimentel-Rodrigues and Siva-Afonso (2019); Hopkinson et al. (2019)
6	Material stocks	Oezdemir et al. (2017); Heinrich and Lang (2019); Gepts et al. (2019); Ali (2019); Ajayabi et al. (2019); Arora et al. (2019)
6	Circular Economy in the project design	Swift et al. (2017); Sanchez and Haas (2018b); Akanbi, Oyedele and Akinade (2018); Akanbi, Oyedele and Akinade (2019); Bertino et al. (2019); Kyrö, Jylhä and Peltokorpi (2019)
5	LCA Analysis	Hossain and Ng (2018); Eberhardt, Birgisdóttir and Birkved (2019a); Eberhardt, Birgisdottir and Birkved (2019b); Krause and Hafner (2019); Rasmussen, Birkved and Birgisdóttir (2019)
3	Material passports	Sauter et al. (2018); Honic, Kovacic and Rechberger (2019); Munaro et al. (2019)

SOURCE: The authors (2020).

4.3.2.4 List of Circular Economy practices by life cycle stage

Another analysis that was possible after this literature review, was the creation of a list of different types of Circular Economy practices that exists focused on the built environment. This list becomes important to the development of this area in the construction sector as several authors (ADAMS et al. 2017; HUANG et al., 2018; van BUEREN; LEENDERS; NORDLING, 2019) have shown that there is a lack of known standard practices to implement Circular Economy in the Construction Industry.

TABLE 4 was done by listing the found practices in the 45 articles used in the literature review, separating each practice in its life cycle stage. However, this separation is not absolute, since most of these practices can be done in different life cycle stages but were listed on their main phase.

TABLE 4 – CIRCULAR ECONOMY PRACTICES FOR THE CONSTRUCTION INDUSTRY

Life Cycle Stage	Circular Economy Practices	References
Project Design	Design and use of modular buildings	Kyrö, Jylhä and Peltokorpi (2019)
	Design for adaptability of existing buildings	Mangialardo and Micelli (2018); Maerckx et al. (2019); Geldermans (2016); Sanchez and Haas (2018)
	Design for Disassembly of building structures	Leising, Quist and Bocken (2018); Mangialardo and Micelli (2018); Maerckx et al. (2019); Eberhardt, Birgisdottir and Birkved (2019b); Rasmussen, Birkved and Birgisdóttir (2019); Sanchez and Haas (2018); Manelius, Nielsen and Kauschen (2019); Nijgh and Veljkovic (2019); Eberhardt, Birgisdottir and Birkved (2019c)
	Use of a scale to analyze the level of implementation of Circular Economy practices in the company	Nuñez-Cacho et al. (2018)
	Use of a simulation in a BIM model to analyse the reuse potential of the materials of different types of designs early in the project.	Akanbi, Oyedele and Akinade (2018); Akanbi, Oyedele and Akinade (2019)
	Use of Life-cycle analysis to find the benefits of reusing different types of materials in the design stage	Eberhardt, Birgisdóttir and Birkved (2019a); Eberhardt, Birgisdottir and Birkved (2019b); Hossain and Ng (2018)
	Use of material stock data to help reuse of materials of a new building	Oezdemir et al. (2017); Heinrich and Lang (2019); Gepts et al. (2019); Ajayabi et al. (2019); Arora et al. (2019); Manelius, Nielsen and Kauschen (2019)
Manufacture	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building	Swift et al. (2017); Leising, Quist and Bocken (2018)
	Development of material passports	Leising, Quist and Bocken (2018); Sauter et al. (2018); Honic, Kovacic and Rechberger (2019); Munaro et al. (2019)
	Reuse of secondary materials in the production of building materials	Nußholz, Nygaard and Milios (2019)
Construction	Reuse of building materials in a new construction	Smol et al. (2015); Sanchez and Haas (2018b); Mangialardo and Micelli (2018); Tallini and Cedola (2018); Maerckx et al. (2019); Rasmussen, Birkved and Birgisdóttir (2019); Ajayabi et al. (2019); Nordby (2019)
	Waste reduction	Esa et al. (2016); Adams et al. (2017)
	Off-site construction	Adams et al. (2017); Minunno et al. (2018); Mangialardo and Micelli (2018)
Operation	Use of a tool to evaluate the state of materials during the lifespan and end of life of a building	Akanbi, Oyedele and Delgado (2019)
	Use of water management practices	Pimentel-Rodrigues and Siva-Afonso (2019)
	Minimize recuperative maintenance with preventive maintenance	Adams et al. (2017)

End of Life	Analyze the potential for reuse or recycling of existing materials and if it is feasible comparing to using new materials.	Sanchez and Haas (2018b)
	Management of demolition waste	Ghisellini, Ripa and Ulgiati (2018); Maerckx et al. (2019)
	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment	Bertino et al. (2019)
	Deconstruction of building structures and parts	Adams et al. (2017); Hopkinson et al. (2019)

SOURCE: The authors (2020).

This list can help the development of Circular Economy on the Construction Industry, since it gives practical steps that a company can take in order to implement CE in their projects, as well as help further the research on this theme.

4.4 DISCUSSION

The discussion of the obtained results is divided into three separate items. First, a descriptive discussion related to the bibliometric results is conducted, followed by a content discussion of all six areas of research included in this study. Finally, the research gaps found in this literature review are discussed.

4.4.1 Descriptive discussion

The bibliometric data of this literature review showed the great increase in the research of Circular Economy in the Construction Industry, mostly on the last three years, when the number of published papers has more than doubled every year. The reasoning behind the great number of publications in 2019 was the event “Building as Material Banks (BAMB) – A pathway for a circular future” that happened earlier in the year.

This event was part of the a project initiated in Europe with 15 partners from 7 different countries called BAMB – Building As Material Banks, that has the goal of “enabling a systemic shift in the building sector by creating circular solutions” (BAMB, 2016) and focuses mostly on Building Material Passports and Reversible Building Design (RBD), in which a project should consider all life cycle stages, guarantee high reuse and transformation potential of the building (BAMB, 2017c).

Other than that, the biggest number of publications comes from two journals that are classified as Q1 in the Scimago Journal Rank (SJR), “Journal of Cleaner Production” and Resources, Conservation & Recycling”. This shows the interest of important sources of knowledge in the built environment research world.

With this increase of interest in the area shown by the bibliometric numbers, we believe there is a need to help unite authors to further the developments of researches in the Circular Economy for the Construction Industry by creating a Community of Practice (CoP) for this area.

Community of Practice is considered an efficient management system to create and share knowledge, regardless of the place, either physical or digital (SARTORI, 2012). This concept started with the definition of Lave and Wenger (1991) that a CoP is a group of relationships between people, activities and the world. Later, Wenger (1998) defined CoP as a group of individuals that share the same interests or passions, aiming at improving their knowledge, information sharing and problem resolutions.

Wenger et al. (2002) described the three main elements of a Community of Practice: (1) Domain, that is the subject which the members have identified themselves with; (2) Community, that is the interactions between the members inside the defined domain; and (3) Practice, in which the sharing of information happens to improve the community knowledge in the domain. TABLE 5 describes the three main elements developed by Wenger et al. (2002) with the focus on the development of Circular Economy in the built environment.

TABLE 5 – ELEMENTS OF A POTENTIAL COMMUNITY OF PRACTICE

Elements	Description
Domain	Circular Economy for the Construction Industry
Community	Universities and Organizations within the Construction Industry
Practice	Development of researches and studies to further the adoption of Circular Economy in the construction sector

SOURCE: The authors (2020).

The potential creation of a Community of Practice can help further research in the practices of Circular Economy inside the Construction Industry, since will help researchers around the world communicate and share their researches and progress, as well as finding other professionals who are studying and developing studies on the same subject.

4.4.2 Content discussion

This step of the discussion is divided into the six found areas of research inside the theme: (1) Development of Circular Economy in the built environment; (2) Reuse of materials; (3) Material stocks; (4) Circular Economy in the project design; (5) LCA Analysis; and (6) Material passports

4.4.2.1 Development of Circular Economy in the built environment

This group of articles is about researches that were concerned with the implementation and development of the concepts of Circular Economy in the Construction Industry, with multiple papers (ESA; HALOG; RIGAMONTI, 2016; ADAMS et al., 2017; LEISING; QUIST; BOCKEN, 2018; HUANG et al., 2018; MANGIALARDO; MICELLI, 2018; CHANG; HSIEH, 2019; van BUEREN; LEENDERS; NORDLING, 2019) investigating the barriers, challenges and opportunities to the use of these concepts in the built environment of their countries.

The overall finding about the level of awareness inside the Construction Industry about Circular Economy seems good, however these concepts are being introduced in the built environment in a slow manner, since most of the stakeholders don’t understand how the concepts can be applied in a practical way for the Construction Industry (ADAMS et al., 2017; EBERHARDT; BIRGISDÓTTIR; BIRKVED, 2019c). Eberhardt, Birgisdottir and Birkved (2019c) also found that the lack of knowledge on how to implement Circular Economy in the Construction Industry is due to the complexity of the supply chain and the short-term goals of most companies, not giving the needed attention for the end of life stage.

To help the understanding of how these concepts can be adopted in the built environment, Pompani and Moncaster (2017) defined the Circular Economy concept for the Construction Industry considering six different dimensions: governmental, economic, environmental, behavioural, societal and technological. Those dimensions were needed, since the authors found that the study of Circular Economy for the built environment has been focusing too much on the global vision of cities or the construction materials, and not enough on the buildings themselves. With the division of those six dimensions, the authors provided a basis for researchers in the development of this concept for the Construction Industry

Other than that, a lack of standards for use of these concepts also hurts its adoption (HUANG et al., 2018), as well as the need to the development of a better waste management of C&D in developing countries (ESA; HALOG; RIGAMONTI, 2016). In terms of opportunities to increase the adoption of Circular Economy in the construction sector some authors (HUANG et al., 2018; Van BUEREN; LEENDERS; NORDLING, 2019; CHANG; HSIEH, 2019) agree that the government could play an important part, with financial and other types of incentives for companies that uses practices of reuse or disassemble in their operations.

Additionally, this area of research included articles that analyzed real cases where Circular Economy concepts have been used in their operations (LEISING; QUIST; BOCKEN, 2018; MANGIALARDO; MICELLI, 2018; MAERCKX et al., 2019) to understand how they were used and what benefits they brought to the projects.

4.4.2.2 Reuse of materials

This area of research was defined for articles that had the focus of its research on the reuse of materials in the built environment, with a total of 12 papers. These studies can be divided into three different levels in Construction Industry. Firstly, the micro-level included the studies that covered applications or methods to reuse specific materials. Sanchez and Haas (2018a) and Nijgh and Veljkovic (2019) conducted researches about new methods of reuse, while Smol et al. (2015) and Tallini and Cedola (2018) studied the possible applications for the reuse of materials through the existing literature.

Secondly, the meso-level includes researches that covered applications of reuse in the whole building, not focusing only on specific materials or elements. Manelius, Nielsen and Kauschen (2019) analyzed a real case of buildings that reused materials in its construction and Pimentel-Rodrigues and Siva-Afonso (2019) discussed the possibilities of applications of reuse in the operation phase of buildings, while Akanbi, Oyedele and Delgado (2019) developed a method to measure the level of reusability of materials in the end of life stage of a building.

Finally, the macro-level included papers that focused on the reuse potential of materials for the Construction Industry. Geldermans (2016) researched the prerequisites that materials need to be reused in the built environment, Nußholz, Nygaard and Milios (2019) analyzed the potential benefits of reuse to reduce carbon emissions in the industry and Nordby (2019) identified the barriers and opportunities for reuse in Norway.

This division of different levels of analysis for the reuse of materials in the built environment and balanced number of publications (4, 3, 3, respectively) shows that research in this area has not focused in only one level of reuse and is committed to develop better methods and ways of reuse in all levels of the Construction Industry.

Another type of research taken in this area was through a literature review, as Ghisellini, Ripa and Ulgiati (2018) and Hopkinson et al. (2019) found that recycling is still the most researched practice for non-disposal methods in the Construction Industry, showing the need to improve the research into reducing and reusing materials before recycling them.

4.4.2.3 Material stocks

In the research area of material stocks, the articles focused on the creation of models to estimate the existing or future quantity of materials that can be reused on buildings in their end of life. Most of the papers created models to estimate the material quantity of specific regions (OEZDEMIR; KRAUSE; HAFNER, 2017; HEINRICH AND LANG, 2019; GEPTS et al., 2018; AJAYABI et al., 2019), differing in the methods and data used to estimating the missing values.

Oezdemir, Krause and Hafner (2017) extracted data from GIS and material values from the literature, while Heinrich and Lang (2019) used geometric data from a city 3D model, as well as material data from the literature. In their study, Gepts et al. (2019) combined two existing data to create the material stock, an EPC (Energy Performance Certificate*)* database and a marketing agency specialized in the construction sector.

The consensus from this group of articles is that it is possible to create material stocks of a city scale with the existing data, however it is still needed more research on the material properties to reliably estimate the percentage that can actually be reused and be considered on the material banks of cities.

4.4.2.4 Circular Economy in the project design

One of the most discussed subjects in articles through all areas of research is that the concepts of Circular Economy should be introduced in the early stages of a project, in its design phase, and this specific group of six articles had their focus on developing tools or understanding the changes that need to happen for CE be implemented in the design phase of buildings.

Half of the articles in this group (SWIFT et al., 2017; AKANBI; OYEDELE; AKINADE, 2018; AKANBI; OYEDELE; AKINADE, 2019) discussed the use of these concepts in the design phase of the project in collaboration with BIM tools. This process has the capability of storing different types of information in its digital model, becoming an important tool for the adoption of Circular Economy in the built environment. Akanbi, Oyedele and Akinade (2018) developed a BIM-based Whole-Life Performance Estimator (BWPE) to analyse in the design phase the recoverability of materials at end of life of the building. Later, Akanbi, Oyedele and Akinade (2019) developed a plug-in for Revit that helps Design for Disassemble (DfD). Also, with use of the BIM process, Swift et al. (2017) studied the utilization of RFID physical tags to change ownership of components of buildings inside BIM data, helping manage the components in their whole life cycle.

Kyrö, Jylhä and Peltokorpi (2019) and Bertino et al. (2019) also studied the use of Circular Economy in the design phase but analysing real cases where the Circular Economy concepts were utilized from the start of the project. This was the main discussion of Sanchez and Haas (2018b), that suggested that projects that use Circular Economy should have distinct phases in the design stage, with decision gates and planning methods.

This area of research shows the potential that exists to implement Circular Economy practices at very early stages of a project, incorporating BIM tools that allow analysis of how different materials can affect the reuse potential of a building, but not only using BIM tools, as it is also very beneficial to design structures to disassemble in the project phase to allow a bigger percentage of materials and structures that can be reused at end of life of buildings.

4.4.2.5 LCA Analysis

This area of research included articles that studied how can Circular Economy be used in Life Cycle Assessments (LCA) and what are the benefits and results of this. Four papers of the five articles in this group conducted a LCA with concepts of Circular Economy.

Eberhardt, Birgisdottir and Birkved (2019b) and Rasmussen, Birkved and Birgisdóttir (2019) performed a LCA for buildings that used Design for Disassembly, concluding that this practice can have great results on the environmental embodied impacts of the buildings, however specifically on the EN 15804/15978 standards the practices didn’t bring advantages, since these standards have the focus on reducing emissions, rather than crediting future emission savings.

Eberhardt, Birgisdóttir and Birkved (2019a) also analyzed a LCA that used compared the results of a linear approach to a circular one of three different components of a building, finding that material loops will not be 100% circular, as there is a need to input materials in order to keep the original materials in the loop, given the system losses. Additionally, Hossain and Ng (2018) found that the majority of LCA’s do not account for reuse possibilities or any type of waste management.

Another focus of analysis in this area was the Module D of a LCA, that brings the summary of all benefits and loads outside the system boundaries. Krause and Hafner (2019) conducted a LCA using this module and found that it can provide information about the recycling potentials at the end of life of a building, however it only contributes to around 3-4% of the overall results of the LCA.

Although the use of LCA tools and methods within the built environment have been increasing over the last years (EBERHARDT; BIRGISDÓTTIR; BIRKVED, 2019a), there is a potential and need to start incorporating more Circular Economy concepts in these analyses. The results of three articles of this area (EBERHARDT; BIRGISDÓTTIR; BIRKVED, 2019a; EBERHARDT; BIRGISDOTTIR; BIRKVED, 2019b; KRAUSE; HAFNER, 2019) shows the benefits of including practices such as design for disassemble in the LCA, as it can reduce the value of embodied carbon and energy in buildings.

4.4.2.6 Material passports

This last area of research included three articles, which the focus was on investigating the creation of Building Material Passports (BMP), that can be used to store important data of these building components for their use in their end of life, helping incorporate the materials in the circular loop, instead of disposing them.

To help the development of BMPs, Sauter et al. (2018) proposed two different ontologies for building materials, named Circular Exchange and Circular Materials and Activities, with the goal of aligning product descriptions and increasing material circulation in the built environment. They also developed a procedure to publish circular data as Linked Data (RDF), incentivizing users, organizations and organizations to publish their material data as RDF.

Honic, Kovacic and Rechberger (2019) created a BMP for a building with different variants to analyse its environmental impacts, where they found that in the studied case concrete had a better recycling potential than timber. Munaro et al. (2019) also developed a BMP in their research, but for the wood frame system in the Brazilian industry. They found that the lack of need for Environmental Product Declarations (EPD) in the country makes it hard to create a BMP, showing the need for building material manufacturers to create EPDs for its materials in order to make it viable for the creation of BMPs.

The existence of a consolidated database of BMPs can help the evaluation and optimization of recycling potential and environment impacts (HONIC; KOVACIC; RECHBERGER, 2019), which comes to the agreement of other areas of research showing the immense potential of using Circular Economy tools and practices earlier in the project to reduce the negative environment impacts constructions can have. However, there are still problems in the process of creating BMPs, as Munaro et al. (2019) described a series challenges in the political, commercial and social areas that still need research and better collaboration between stakeholders to make this process more accessible and feasible.

4.4.3 Research gaps

After the development of this literature review, this section will describe the knowledge gaps still existing in the use of Circular Economy for the Construction Industry.

Although the biggest number of publications in one area was about the reuse of materials, one of the most common barriers for the adoption of Circular Economy concepts was the lack of standard practices for the reuse of those materials (ADAMS et al. 2017; HUANG et al., 2018; van BUEREN; LEENDERS; NORDLING, 2019). This shows the existing need for research to develop more standard practices about the reuse of building materials that can be proved and adopted by the industry.

Another area that needs more development in the academia is in the creation of Building Material Passports. This literature review found just three articles in that area, in which only two had the goal of creating a BMP. This shows the need for more research on understanding the prerequisites and barriers existing in the process of creating a BMP from the academia, given the low number of articles in this area. This knowledge gap, however, has been explored by the BAMB project and has already had a number of useful reports on the guidelines and results obtained (BAMB, 2017a, 2017b, 2018, 2019a, 2019b, 2019c), which could help the development and establishment of this practice in the construction industry.

Additionally, one area of research that was not included in this literature review but still needs attention in the Circular Economy is the development of business models within the Construction Industry. The current models are still supporting the linear use of resources (BAMB, 2017c), in which the construction company only cares about the resources that will be used for the construction, not giving the importance it needs for the end of life of the materials.

This paradigm shift for a circular use of resources needs to happen in the Circular Economy, and with this more business models opportunities will arise, since new business services will be needed, such as companies that support the collection of materials at end of their life, companies that specialize in disassembling materials and structures to be reused, among others (EMF, 2015). With more different business services emerging from this concept, there is a big need of researching how the current business models of construction companies can adapt to this change.

4.5 CONCLUSIONS

This article had the objective of finding the recent developments of Circular Economy in the Construction Industry, and a systematic literature review was conducted to reach this goal. In total 45 articles were included in the review after the creation of a bibliometric network that gave the three most relevant cited terms in Circular Economy researches for the construction sector.

Through the literature review, it was possible to divide the papers into six different areas of research inside this subject. The one that had the biggest number of publications was about the development of Circular Economy in the built environment. The other research areas found were, in order of number of publications: reuse of building materials at their end of life stage, material stocks, Circular Economy in the project design, LCA analysis and material passports.

From the development of Circular Economy in the built environment research area, the consensus is that there is good level of awareness of the need of change from the linear to the Circular Economy, however practitioners argue about the lack standardized methods and practices to help them implement in their construction projects.

The reuse of materials area of research shows the need to study how building materials can be reused in different levels, analysing the materials for the Construction Industry in general, their materials in specifically for buildings and for each specific material as well.

The following area of research, material stocks, found that it is possible to create material stocks in a large scale, such as a whole city, by the means of existing data. This possibility, however, needs further research to improve the reliability of the percentage of existing building materials that will be possible to reuse.

Throughout most of the 45 articles reviewed in this research, the necessity to implement Circular Economy concepts from the project design phase has been emphasized. The potential to consider those concepts in the earlier stages of a project can help assess the reuse percentage of the materials that will be used and help decision makers choose the most fitting materials in the circularity mentality, as well as better manage all the resources that will be used throughout the life cycle of the building.

By considering the Circular Economy practices earlier in the project design stage, there is also the possibility of incorporating them into the LCA analysis of the project. This will help show the benefits of reusing materials and reducing the amount of resources taken from the nature, with the results of reducing emissions, embodied carbon and energy in the project.

After analysing the content of the selected articles, the biggest knowledge gaps and research opportunities were given. There is a need to further the development of standard practices for the reuse of building materials, as several articles found this fact as one of the biggest barriers for the adoption of Circular Economy in the Construction Industry. To help in this gap, this review created a table of known CE practices in each life cycle stage, that were described in the 45 articles. Also, a bigger attention should be given to research the needs and challenges on the creation of Building Material Passports, as well of in the development of new business models that use the Circular Economy approach in their operations.

Another analysis made was regarding the bibliometric data of the articles in this review. Over the last three years the number of publications has more than doubled every time, and the places that had the biggest number of articles are important sources of knowledge sharing in the construction sector. These facts showed that the concept of Circular Economy has been gaining a lot interest in the built environment and we found the need to create a Community of Practice for this area of research, to help develop and increase its adoption in the Construction Industry.

Although not included in the list of 45 articles included in this literature review since it only included peer reviewed and proceeding papers, the project BAMB has been helping the development of the implementation of Circular Economy in the Construction Industry. Throughout a series of reports and pilot projects, this EU funded project contributes with practical cases of how the implementation of CE practices happens and their results, and should be considered and explored by practitioners that want to apply CE into their businesses.

Finally, this article brings to attention the fact that most of the 20 practices found for the Circular Economy in the Construction Industry are aiming at reducing the amount of waste generated at the end of the life cycle of a building, as well as better manage the resources used throughout it. These two results are very similar to the end goals of Lean Construction, that looks to eliminate waste along the construction and improve the efficiency of the process (KOSKELA, 2000). Nadeem (2019) states that the similarities between Lean Thinking, the concept behind Lean Construction, and Circular Economy have the potential to produce good results, therefore is something that can be explored and better studied.

The summary of each article included in this literature review is given in Appendix 1, as it can help better understand the contents of each research. Following, Appendix 2 gives the main contributions of each study contemplated in this literature review.

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APPENDIX 1 – SUMMARY OF EACH ARTICLE INCLUDED IN THE LITERATURE REVIEW

Articles	Area of Research	Summary
Swift et al. (2017)	Circular economy in the project design	Switft et al. (2017) conducted a research that studied how the RFID technology can help changing the ownership of components parts of buildings, so they can be easily reused or readapted, through BIM data and physical RFID tags in three case studies.
Sanchez and Haas (2018b)	Circular economy in the project design	Sanchez and Haas (2018b) discussed the shift that needs to happen in the project planning for capital projects, from linear to circular economy. The authors suggest that capital projects delivery phases should have distinct phases, decision gates and planning methods, as disassembly or LCA protocols.

Akanbi et al. (2018)	Circular economy in the project design	Akanbi et al. (2018) developed a BIM-based Whole-life Performance Estimator (BWPE) to analyse the recoverability of structural components of buildings in the design phase, as a potential tool to help decision makers in the early stages of the project.
Akanbi et al. (2019a)	Circular economy in the project design	Akanbi et al. (2019a) developed a Revit plug-in to analyze the disassemble and deconstruction capabilities of materials, helping introduce this concept in the project design phase in combination with BIM platforms.
Bertino et al. (2019)	Circular economy in the project design	Bertino et al. (2019) presented a case study of a existing building in Vienna that suffered multiple interventions with the concept of circularity in mind, in a project called HOUSEFUL, to reduce the negative impacts on the management of materials, water, waste and energy of the building.
Kyrö et al. (2019)	Circular economy in the project design	Kyrö et al. (2019) analyzed multiple case studies of relocatable modular buildings in Finland through semi-structured interviews, developing a framework for usable and relocatable modular buildings, helping the circularity of construction.
Esa et al. (2016)	Development of circular economy	Esa et al. (2017) researched about the use of the concept of circular economy to minimize CDW, conducting a literature review about how can CE be operationalized as a way to minimize wastes and developed a CE-based framework for this purpose in a micro, meso and macro level.
Adams et al. (2017)	Development of circular economy	Adams et al. (2017) conducted a research about the level of awareness of circular economy between the different stakeholders in the United Kingdom construction section through a quantitative and qualitative survey.
Pomponi and Moncaster (2017)	Development of circular economy	Pomponi and Moncaster (2017) conducted a literature review on the definitions of circular economy for the built environment and all of its dimensions considered in the previous literature, focusing on the least researched level of circular economy, the meso-level, that the authors state that are the buildings.
Leising et al. (2018)	Development of circular economy	Leising et al. (2018) analyzed three case studies in the Dutch construction sector that used principles of circular economy, to understand the level of collaboration between the supply chain of the industry and develop a collaboration tool to boost the use of circular economy, creating five phases for the project: preparation and vision, involvement of the market, design and collaboration, business model and implementation, and usage and preparation for next uses.
Huang et al. (2018)	Development of circular economy	Huang et al. (2018) conducted a research about the adoption of the 3R concept (redection, reuse and recycling) of construction and demolition waste in China, through a literature review and personal interviews the authors found the biggest barriers to the use of each of those three concepts in the country.
Mangialardo and Micelli (2018)	Development of circular economy	Mangialardo and Micelli (2018) analyzed through three different case studies on Europe how can the Construction Industry introduce and apply the concepts of circular economy and how it will transform itself.
Minunno et al. (2018)	Development of circular economy	Minunno et al. (2018) conducted a literature review on how the circular economy can be applied to different industry sector to find how can it be used in the prefabricated sector of built environment, resulting in seven guidelines for this application.
Nuñez-Cacho et al. (2018)	Development of circular economy	Nuñez-Cacho et al. (2018) developed a circular economy scale for the building industry, to measure the degree of implementation, using seven different weighted dimensions, four related to waste management, two related to environmental impacts and one with indicators about the transition to a CE.
Chang and Hsieh (2019)	Development of circular economy	Chang and Hsieh (2019) conducted an interview and case study to disclose the current development of circular economy in Taiwan, finding its barriers and potentials for its use in the construction sector.
Eberhardt et al. (2019c)	Development of circular economy	Eberhardt et al. (2019c) conducted a literature review to identify the main challenges of implementing circular economy within the construction industry, as well as analyzing a case study of a Danish office building that was designed to disassemble to quantify its potential environmental and economic benefits.
Maerckx et al. (2019)	Development of circular economy	Maerckx et al. (2019) conducted an overview of 14 awarded projects from the Brussels Regional Program for a Circular Economy, which focused on better management of human and material resources, exploring the reuse, design for disassembly, training of workers and partnerships that those projects used.
van Bueren et al. (2019)	Development of circular economy	van Bueren et al. (2019) conducted an interview with several stakeholders of different projects in Taiwan that had the goal of introducing circular economy in the sector, understanding its existing barriers and obstacles.
Ünal et al. (2019)	Development of circular economy	Ünal et al. (2019) proposed a theoretical framework for creating value within a circular economy model, based on managerial practices, and applied to a study case of a small medium-size enterprise in the building sector.
Hossain and Ng (2018)	LCA Analysis	Hossain and Ng (2018) conducted a literature review about a number of LCA studies and circular economy in the built environment, with aim of finding knowledge gaps for the adoption of CE in the construction sector, as the authors developed a framework based on this review to extend the scope of research in this area and help the adoption of CE.

Eberhardt et al. (2019a)	LCA Analysis	Eberhardt et al. (2019a) researched about the concept that life cycle assessments (LCA) are usually modeled linearly, that goes against the concept of circular economy. Because of that, the authors conducted two LCAs for three different materials, one using the linear approach and another incorporating circular perspectives as reuse and recycling.
Eberhardt et al. (2019b)	LCA Analysis	Eberhardt et al. (2019b) conducted a life cycle assessment of a Danish office building that used a concrete structure that was designed for disassembly (DfD) to compare with traditional building methods.
Krause and Hafner (2019)	LCA Analysis	Krause and Hafner (2019) performed a LCA analysis of exemplary buildings to investigate if the final module of the LCA (D) - summary of all benefits and loads outside the system boundaries - can be a suitable source of information for recycling potential of waste materials from demolition.
Rasmussen et al. (2019)	LCA Analysis	Rasmussen et al. (2019) conducted a LCA using the EN 15804/15978 standards to compare how these calculations affect the environmental impacts (in this study GWP) of a building that used primarily upcycled materials and a building that was designed for disassembly (DfD).
Sauter et al. (2018)	Material passport	Sauter et al. (2018) proposed two different building material ontologies, Circular Exchange and Circular Materials and Activities to facilitate material circulation in the construction sector, giving the materials the necessary elements for material exchange happen, in order to create building materials passport.
Honic et al. (2019)	Material passport	Honic et al. (2019) developed a Material Passport of a case study building with two different variants, one that used concrete and the other timber, to compare the environmental impacts and the recycle potential of each variant.
Munaro et al. (2019)	Material passport	Munaro et al. (2019) developed a Building Material Passport of the wood frame system for the Brazilian industry and used the created BMP in a case study of a wood frame specialized company to analyze the feasibility of this BMP, as well as investigating the main challenges to implement a Material Passport in the built environment.
Oezdemir et al. (2017)	Material stocks	Oezdemir et al. (2017) developed a framework to assessing the material stock available in residential buildings in a urban region of Germany, by extracting the data from GIS and reviewing this data with previous studies about the material values, creating a cadaster of secondary resource that will be available to reuse in the future.
Heinrich and Lang (2019)	Material stocks	Heinrich and Lang (2019) developed a model to calculate the material stocks in the district of Munich, Germany, using geometric data from the city 3D model and material specific data, finding the potential date for several material self-sufficiency.
Gepts et al. (2019)	Material stocks	Gepts et al. (2018) studied the existing databases of building materials in Belgium to combine them in creating a material bank of the existing building stock, but only as a starting point of this data, since extra checks and data are needed to create a more accurate dataset for material banks.
Ali (2019)	Material stocks	Ali (2019) created a framework that aims at including material reuse decisions on the project design of a new building, using a BIM platform to calculate all the materials needed for the new building and comparing with data from close sites of buildings that have been or are in process of being de-constructed.
Ajayabi et al. (2019)	Material stocks	Ajayabi et al. (2019) conducted a research inside the 3 year project called REBUILD in the UK, that aims at quantifying the existing material stocks and flows of buildings, new demolition techniques to optimize the amount of material that can be reused, quantification of the potential of reuse and defining optimized circular system elements in the built environment. In this particular paper the authors focused on the first two goals, quantifying the existing material stocks for a city and finding new techniques for the extraction of bricks in demolition.
Arora et al. (2019)	Material stocks	Arora et al. (2019) developed a methodology to estimate material and component stock of public housing in the city-state of Singapore using a bottom-up stock analysis, in order to enhance the potential for secondary resource recovery.
Smol et al. (2015)	Reuse of materials	Smol et al. (2015) discussed the different applications existing in the literature for the use of sewage sludge ash (SSA) for the manufacture of building materials, in order to make this chain more circular.
Geldermans (2016)	Reuse of materials	Geldermans (2016) conducted a research with the goal of finding the prerequisites for effective performance of materials, for them to be used and reused in a circular manner in the built environment. It was based on four workshops with different types of stakeholders, creating preconditions and guidelines to help this practice.
Ghisellini et al. (2018)	Reuse of materials	Ghisellini et al. (2018) conducted a literature review with the goal of evaluating if the circular economy approach is environmentally and economically sustainable for the C&D waste management.
Sanchez and Haas (2018a)	Reuse of materials	Sanchez and Haas (2018a) developed a new disassembly sequence planning method for adaptive reuse of buildings, using expert rules derived from case studies for buildings.
Tallini and Cedola (2018)	Reuse of materials	Tallini and Cedola (2018) conducted a state-of-art review about the use of waste materials into building materials to enhance its thermal capacities and achieve a Net-Zero Energy Building.
Hopkinson et al. (2019)	Reuse of materials	Hopkinson et al. (2019) conducted a literature review about the recovery and reuse of building products, especially the ones involved in the structure of buildings, as steel, bricks and concrete, analyzing its techniques for recovery at the end of life service of buildings to reuse them, as well as their environmental impacts.

Nordby (2019)	Reuse of materials	Nordby (2019) studied the current level of reuse in the Norwegian construction sector, identifying its technical and legal barriers, and providing new opportunities to help grow the reuse in the country, as a legal framework, economic incentives, competence and awareness, information system and control schemes.
Nußholz et al. (2019)	Reuse of materials	Nußholz et al. (2019) conducted a research about the use of secondary material in the construction sector with the goal of minimizing carbon emissions of buildings, finding that this use can reduce the emissions, varying with the type of material.
Manelius et al. (2019)	Reuse of materials	Manelius et al. (2019) conducted a research about three case studies of constructions that used high percentage of reused material in its constructions, through qualitative surveys with the architects of these projects.
Nijgh and Veljkovic (2019)	Reuse of materials	Nijgh and Veljkovic (2019) developed a way of making composite floor structures demountable and reusable, using injection bolts, under laboratory conditions, showing that these types of structures can be developed for reusability and circularity.
Akanbi et al. (2019b)	Reuse of materials	Akanbi et al. (2019b) developed a tool for the assessment the status of building materials in the end of life service of the structure, using a reliability analysis principle a mathematical tool was created and tested in a case study.
Pimentel-Rodrigues and Siva-Afonso (2019)	Reuse of materials	Pimentel-Rodrigues and Siva-Afonso (2019) discussed the different possibilities of using the concept of circular economy in the operation phase of buildings to manage the water as a resource, such as new green roof solutions and rainwater harvesting systems for buildings.

APPENDIX 2 – MAIN CONTRIBUTIONS OF EACH ARTICLE INCLUDED IN THE LITERATURE REVIEW

Articles	Area of Research	Contributions
Swift et al. (2017)	Circular economy in the project design	• It was possible to connect data from a physical component through RFID tag to BIM.
		• The use of tags in new or existing buildings can help service manage components over the life cycle, checking their performance and taking them back for updates or repairs.
Sanchez and Haas (2018b)	Circular economy in the project design	• A capital project planning framework was proposed for closed-loop cycle in construction projects.
		• The authors argue that capital projects delivery phase should have distinct stages, decision gates, definition confidence categories and planning methods.
Akanbi et al. (2018)	Circular economy in the project design	• Results showed that building design with steel structure, demountable connections and prefabricated assemblies generate the most reusable materials.
		• Building materials with concrete structure generates mostly recyclable materials.
		• Tool that can be used in the design phase to evaluate the potential for reuse of the materials chosen in the design
Akanbi et al. (2019a)	Circular economy in the project design	• A system architecture for evaluating building design for performance analysis of the end of the life was designed.
		• A BIM tool was developed, as a Revit plug-in, to help the assessment of a building designs' level of implementation and use of circular economy principles and objectives.
Bertino et al. (2019)	Circular economy in the project design	• The project aims at reducing the amount of waste destined to landfills (from 40% to 10% in ten years).
		• Provided new circular solutions for the construction sector.
		• Created new economic models for circular economy in the EU market.
Kyrö et al. (2019)	Circular economy in the project design	• Through the literature review it found the characteristics of modular buildings that supports circularity, namely the adaptability of the modules with multifunctionality and elasticity, the location within existing urban structure and lack of burden of ownership.
		• Modular buildings must comply with the following elements of circular economy: resource efficiency, preserving and extending what is already made, designing for the future, and rethinking the business model.
Esa et al. (2016)	Development of circular economy	• A framework based on the concept of circular economy to minimize CDW in Malaysia was developed in a three-layer approach, micro-, meso- and macro-level.
		• The micro-level should focus on transforming the traditional method of construction, in a way that waste could be reduced. In a meso-level the procurement methods should be changed to better manage wastes. In macro-level it should be provided better monitoring and coordinating mechanisms to ensure that the waste management is well implemented and controlled.

Adams et al. (2017)	Development of circular economy	• At an individual level there was a good sense of awareness about circular economy, however there was a lack of consensus of what circular economy means in terms of the built environment. • The lack of incentives to design the project for end of life issues and lack of market mechanisms to aid greater recovery were the biggest challenges found by the authors.
Pomponi and Moncaster (2017)	Development of circular economy	• The authors were able to create a frame of reference for the definition of circular economy in the built environment level, that considers six dimensions: governmental, economic, environmental, behavioral, societal and technological.
Leising et al. (2018)	Development of circular economy	• The authors found five ways for the supply chain collaboration to achieve more circular buildings: (1) vision development of the whole lifecycle of a building through clients and stakeholders; (2) actor learning to broaden the scope of the parties involved into including end-of-life solutions early into development; (3) facilitating supply chain collaboration by bringing all partners together; (4) use of new sustainable business models, that extends the ownership of the elements involved in the supply chain through the lifecycle of the building; and (5) a new design process is needed to include the supply chain in the development of the vision of the building with the clients.
Huang et al. (2018)	Development of circular economy	• The biggest challenges found by the authors the adoption of 3R concept in China were the lack of a building design standard for reducing CDW, low cost to dispose CDW and bad urban planning. • To reduce CDW it is important to reinforce source control, supervision and management, and new technologies should be essential to promote the use of circular economy in the built environment.
Mangialardo and Micelli (2018)	Development of circular economy	• The use of high-performance technologies opens new perspectives for the construction industry. • Off-site industrialization increases the energy efficiency of buildings, becoming a great opportunity for construction.
Minunno et al. (2018)	Development of circular economy	• Seven strategies were found from the application of CE in other industries that can be used in the prefabricated sector and their barriers of implementation. • Seven guidelines were developed as potential applications of CE concepts in the building sector
Nuñez-Cacho et al. (2018)	Development of circular economy	• The scale designed can provide information to the company and its stakeholders on the degree of long-term sustainability and CE implementation for the construction company. • It can also be used as a critical analysis tool for the sustainability indicators in the construction sector, as well as for strategic and business management of companies in this industry.
Chang and Hsieh (2019)	Development of circular economy	• Even though the government of Taiwan has made strong emphasis on the use of circular economy in the construction industry, the level of awareness among the stakeholders is still low. • There needs to be an establishment of financial incentives and platforms for material circularity in the industry.
Eberhardt et al. (2019c)	Development of circular economy	• The main challenges of implementing CE in the construction sector are the high complexity of the supply chain and the focus on short-term goals, that create competition between stakeholders instead of collaboration needed to the CE concept. • There is a lack of agreement on the concept of CE that results in a lack of knowledge on how to implement CE in the construction sector. • Different building types and materials might use different CE principles to optimize its benefits.
Maerckx et al. (2019)	Development of circular economy	• In overview of the case studies, the authors found a transfer of investments related to material resources to human resources. • The cases showed that it is already possible to implement circular economy principles in the construction site, but that requires effort and creativity from the stakeholders.
van Bueren et al. (2019)	Development of circular economy	• The cases analyzed showed that academia gains knowledge, industry gains technology and government gains new policies through foreign institutions, making, in the case of Taiwan, a stronger collaboration in order to implement the circular economy concepts in the industry. • The government of Taiwan have the right goals for this implementation, however it still needs to improve its regulations and incentives for construction companies, so it can be adopted more.
Ünal et al. (2019)	Development of circular economy	• Materialistic approach to circular economy that only focus on resources use restricts the potentials for this concept. • The results showed that regeneration, in terms of resources and location, is one of the sources for value creation in the circular economy model.
Hossain and Ng (2018)	LCA Analysis	• Less than half of the LCA studies used in this review took to account the cradle-to-grave approach for their analysis, therefore it is something that should be addressed moving forward, also implementing a more cradle-to-cradle approach to the assessment. • More than two thirds of the studies analyzed did not consider waste management in any part of the analysis, showing the need to introduce these concepts in the assessment in order to achieve a circular economy in the construction sector.
Eberhardt et al. (2019a)	LCA Analysis	• Material loops will not be 100% circular, as additional input materials are needed to keep the original materials in the loop, due to system losses.

		• There is a need for a more consistent LCA approach to implement CE concepts to provide stakeholders a reliable tool for decision-making.
Eberhardt et al. (2019b)	LCA Analysis	• Material composition has a great impact on the embodied environmental impacts and depends on the number of reuse cycles and material's service life.
		• The longer the material's lifespan and its number of reuse cycles, the longer it postpones the need to extract new raw resources.
Krause and Hafner (2019)	LCA Analysis	• Module D provides methods to display information on the recycling potential of materials that were used in the buildings
		• The results from Module D only contribute to 3-4% of the overall results of the LCA.
Rasmussen et al. (2019)	LCA Analysis	• The EN standards points at the upcycling approach with less environmental impacts, as the DfD strategy did not bring an environmental advantage within the standard.
		• The authors concluded that the current standards focus on lowering current emissions rather than crediting potential future emission savings.
		• The development of DfD for concrete components might not be the optimal use for DfD approach, as it should be used on shorter-lived elements to result in higher benefits potential.
Sauter et al. (2018)	Material passport	• A common ontology was developed to align product descriptions and increase material circulation in the construction sector.
		• The authors proposed a procedure to publishing circular economy data in Linked Data (RDF) from existing material passport data.
		• The proposed ontologies should incentivize individual users, organizations and manufacturers to publish data as Linked Data.
Honic et al. (2019)	Material passport	• Concrete showed a bigger (52%) recycle potential than timber (34%) for this studied case.
		• Concrete had a bigger mass of waste (1797 tons) compared to timber (1123 tons).
		• Various aspects should be taken in account when choosing the material to consider the recycling potential of a project, such as the use of lighter construction materials, higher lifespan and high recycling potential.
Munaro et al. (2019)	Material passport	• The lack of necessity of EPDs in the Brazilian construction sector makes it hard to create a complete BMP, as several key information are missing or not disclosed.
		• There are many barriers to the implementation of a BMP in the construction sector, since it requires systemic thinking about value chains and flows, it also needs a better collaboration between stakeholders and government support.
Oezdemir et al. (2017)	Material stocks	• The developed framework can be performed to analyze the recycle potential of any region, however the separation of material composite in existing buildings is not yet possible.
		• The results showed that although material intensity has been reduced recently in buildings, the gross floor area has increased, and the material distribution is the same, something that the authors could not explain in this paper, highlighting the need for further researches to understand this process before extrapolating results.
Heinrich and Lang (2019)	Material stocks	• This study found that from this specific case under certain conditions, it could be achieved a self-sufficiency of steel and recycled concrete from 2036 and 2031, respectively, in the material stock model created for the German district used.
		• With geographical information of materials, it was able to create material stock for secondary raw materials from the existing buildings.
Gepts et al. (2019)	Material stocks	• Through the use of two existing databases, it was possible to create a material bank of a Belgium region while estimating the interior wall area with building volume and typology data.
		• The estimating model developed can be a starting process to the creation of more material banks, but still needs more research to check its suitability for older buildings.
Ali (2019)	Material stocks	• There needs to be paradigm shift from the usual Design-Bid-Build process to include reuse information in the decision making of the project design.
		• In order for this shift to happen, a Unified Virtual Repository database should be created to connect all available physical repositories.
		• This database should be connected with BIM to give decision makers more tools in the project design phase to help the adoption of reused materials in the project.
Ajayabi et al. (2019)	Material stocks	• The research was able to quantify the material intensity of existing buildings in this first stage of the project, but still needs to access the potential for reuse of these materials.
		• The technique used to recover bricks from the case study showed good potential, as they were able to recover around 97% of the bricks without compromising its structure capacity.
Arora et al. (2019)	Material stocks	• The developed methodology can be applied at neighborhood or city-level.
		• There needs to be more collaboration between industrial ecologists, urban developers, planners and policy makers to make use of material stocks more reliable and real.
Smol et al. (2015)	Reuse of materials	• Sewage sludge ash has the potential to be an alternative substitute in construction materials.

		• Product manufacturers in the building sector should look into researching and producing more materials using SSA to avoid disposing it on landfill.
Geldermans (2016)	Reuse of materials	• The intrinsic properties that materials should have to impulse the use in a circular economy is high quality, sustainable origin, non-toxic and consistent with biological cycle. • Seven data categories were identified as preconditions to assess the circularity potential of a material, including composition, performance quality, intended path of use, performance time, connections between materials, dimensioning and quality of the registration system. • The use of materials or principals of circular economy demands very different approaches in the stages of before, during and after the performance span.
Ghisellini et al. (2018)	Reuse of materials	• Environmental impacts more studied than economic impacts. • Recycling is the most researched option of the 3R. • The adoption of circular economy reduces the negative environmental impacts. • There are still a lot of barriers that prevent the use of recycled materials in the construction, as economic, legislative or technical.
Sanchez and Haas (2018)	Reuse of materials	• The paper describes the principles to improve the process of adaptive reuse with a technical approach, with great importance for the disassembly planning. • A new single-target selective disassembly sequence planning framework was developed and validated. • In the case of adaptive reuse of a existing building, specific targeted components should be disassembled for reuse first, then its subsystem can also be disassembled.
Tallini and Cedola (2018)	Reuse of materials	• The use of waste materials for non-structural applications improves thermal performance in terms of reduction of thermal conductivity. • The results revealed that proper addition of selected waste materials can significantly reduce heat loss, improve thermal insulation performance and increase mechanical strength.
Hopkinson et al. (2019)	Reuse of materials	• Most existing studies focus on the recycling rate and its techniques, instead of direct reuse of materials. • Little attention has been given for LCA environmental benefits of material reuse.
Nordby (2019)	Reuse of materials	• The barriers for the reuse in the Norwegian construction sector are still technical, with an undeveloped market for professional actors, lack of information about the use of these materials and an established framework, as well as legal restrictions about the use of these materials. • There are plenty of opportunities to develop the reuse of materials in this sector, as adapting the current legal framework, adding economic incentives, raising the level of awareness, a better information system and marketplace for this practice.
Nußholz et al. (2019)	Reuse of materials	• The results showed that secondary-based products emit 30-50% carbon of their primary correspondents for concrete aggregates and wood-plastics composites, respectively. • Carbon emission savings depends on which harmful processes are replaced in the primary material production with secondary materials and its consequences in the industry chain. • Although all studied cases in this paper showed positive results in terms of reducing emissions, there were notable differences in the amplitude of savings between different strategies adopted.
Manelius et al. (2019)	Reuse of materials	• The authors concluded that cities could maintain their resources as material banks and should exchange this information with other cities. • Temporary projects are optimal opportunities to implement the concept of Design for Disassemble (DfD), since it is their nature to have a small lifespan.
Nijgh and Veljkovic (2019)	Reuse of materials	* The demountability and reusability of a composite flooring system that consisted of steel beams and prefabricated concrete was demonstrated using resin-injected bolted shear connectors.
Akanbi et al. (2019b)	Reuse of materials	• The quality of materials at end of life service of the building varies with the building component. • The results of evaluation of the model provide an efficient tool of maintenance for buildings and the material stock. • This tool provides the amount and quality of materials at the end of life of a building, as well as a tool to evaluate the performance of different designs in terms of circular economy.
Pimentel-Rodrigues and Siva-Afonso (2019)	Reuse of materials	• The use of green roof or rainwater harvesting systems should be used to adapt buildings in the circular use of their resources, such as water.

5 INTERACTIONS BETWEEN LEAN CONSTRUCTION PRINCIPLES AND CIRCULAR ECONOMY PRACTICES FOR THE CONSTRUCTION INDUSTRY

Gabriel Luiz Fritz Benachio

Maria do Carmo Duarte Freitas

Sérgio Fernando Tavares

Abstract: With the recurrent challenge of scarcity of resources in the world, the Construction Industry has been giving more attention to the sustainability aspect over the last decades, since the industry is responsible for a big percentage of waste generated daily as well as a large amount of natural resources extraction. This high use of natural resources is because the Construction Industry still uses the linear economy of "take-use-dispose", that disposes a high amount of material in the end-of-life stage of a building. Opposed to that traditional process, the Circular Economy (CE) looks to better manage the building materials and consider them as valuable resources after the end-of-life of a building, reducing the amount of waste generated. Similarly, the concept of Lean Construction (LC) looks to improve the value of the building, reducing waste and improving productivity in construction, and has been studied since the nineties. Their synergies make their combination possibly bring benefits for the Construction Industry; however, this blend of concepts has not been extensively studied for the built environment. The objective of this research was to find the interactions, positive or not, between the Circular Economy practices and the Lean Construction principles, using the method of content analysis to create a matrix of relations that found a total of 74 interactions, 70 positive and 4 negatives. From these interactions, the LC principle of "reducing the share of non value-adding activities" had the biggest number of interactions with CE practices, the practice of "off-site construction" had the biggest number of interactions with LC principles and the construction stage was the life cycle phase that averaged the biggest number of interactions. Finally, it was possible to identify an optimal project sequence that took use of the CE practices that had the most LC principles incorporated into them.

Keywords: Circular Economy; Lean Construction; Construction Industry; Built environment; Sustainable construction; Reversible Building Design.

5.1 INTRODUCTION

Over the last decades, the Construction Industry has changed their focus on the research of the sustainability of its sector, since it has a huge environment impact and generates a large sum of waste every day (GHISELLINI; RIPA; ULGIATI, 2018). Other than that, the industry also faces the sustainability challenges of high energy usage, carbon footprint, carbon emission and over reliance of resources (SAIEG et al., 2018).

This over use of resources is present because the Construction Industry is still based on a linear economy that takes resources out of the nature to process it and use it in the construction process, to only dispose them in the end of life stage of the buildings, better known as the “take-make-dispose” process (POMPONI; MONCASTER, 2017).

This challenge becomes even more important since the Construction Industry consumes 40% of the materials in the world (KHASREEN; BANFILL; MENZIES, 2009). The European Union required in the 2008/98/EC directive that 70% of all non-hazardous construction and demolition waste be recycled by 2020, but recently this number was only 46% (EUROPEAN COMMISSION, 2016).

To face this problem, the concept of Circular Economy (CE) is a different model that bases its principles in reducing, reusing and recycling, to address more effectively the amount of waste generated by the Construction Industry (HUANG et al., 2018). It proposes a change of mind-set from the current linear approach of generating waste into considering waste as useful resources, increasing the value of them (ANDREWS, 2015). Moreover, EMF (2015) defined CE as “restorative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles”.

In this search to reduce waste, or, in the case of CE, make use of the construction waste, another concept that has been introduced into the Construction Industry is the Lean Thinking, that seeks increasing the value of a product and reducing waste (HOWELL; BALLARD, 1998). This concept was first developed by Taiichi Ohno in the Toyota Production Systems in the sixties (OHNO, 1997) and its adoption to the Construction Industry has been studied since then. The use of this concept for the construction sector gained the name of Lean Construction (LC) in 1993 by the International Group for Lean Construction (IGLC) to describe this concept as “an approach to designing and carrying out construction activities to minimize waste in materials, time and efforts, with the aim of achieving maximum cost-effective value” (BABALOLA; IBEM; EZEMA, 2019).

With these similarities in their concepts of seeking reduction of waste and adding value to the product, Nadeem et al. (2019) explored the possibility to combine both concepts of Lean and Circular Economy in the manufacture sector. They integrated the principles of both concepts and developed a conceptual framework to provide a mechanism for systematic use of CE in the sector. With 14 detailed steps, the authors concluded that this framework allows a company to achieve economic growth with a sustainable approach, increase productivity and market share, between others benefits.

Focusing on the Construction Industry, such study has not been done, therefore there is a need to explore and investigate the interactions that the concepts of CE and LC can have in the Construction Industry. The objective of this research is to find the interactions, positive or not, that the CE practices and LC principles have. The following section gives a background on both concepts, section 3 presents the methods used in this study, section 4 shows the results found, followed by the discussion of them in section 5 and finally, section 6 concludes this study.

5.2 LITERATURE BACKGROUND

This section will give a brief background on the concepts of Circular Economy and Lean Construction, as well as the concepts and principles in which both concepts were derived.

5.2.1 Circular Economy

The concept of Circular Economy has been created from the opposite traditional economy, that exists since the Industrial Revolution, with a linear mentality of “take-make-dispose”, in which raw materials are extracted from the environment, processed, consumed and disposed afterwards (EMF, 2012). This practice has negative impacts on the environment (MILLAR et al., 2019), as it loses a great amount of resources during the production process, disposes most of its materials at the end of life stage of the products, uses a considerable amount of energy to process it and erodes the existing environmental ecosystems (EMF, 2012). Besides these negative impacts, this system also has been increasing the amount of resources taken from the environment every year (EMF, 2012) and since 1971 the society has been taking more resources from the environment than it can generate (SARKIS, 2019).

In face of those negative impacts of the linear mentality of the traditional economy, the concept of Circular Economy has gained a lot of interest both from the industries and the academia, with the help of the reports from Ellen MacArthur Foundation (EMF, 2012, 2013, 2014, 2015), since it promotes the change of mindset to consider waste as a useful resource and not a problem to dispose of (ANDREWS, 2015), aiming to create a circular material loop (GHISELLINI; RIPA; ULGIATI, 2018) with a better management of resources (POMPONI; MONCASTER, 2017).

EMF (2012) developed five main principles that the Circular Economy aims at: (1) Design out waste, in which the design of products must be done with the idea of eliminating all waste; (2) Build resilience through diversity, to make the products more adaptable to the different systems and not require different products, that will use more resources; (3) Rely on energy from renewable sources, since the traditional economy uses a great amount of energy to process the products; (4) Think in “systems”, to consider the products in a whole system and not isolated; and (5) Waste is food, in which every generated waste must be considered a useful resource, whether something the environment can make use of or a resource the industry will use to make new products.

The concept of Circular Economy has been gaining momentum in the Construction Industry, since the circular principles can reduce the negative environmental impacts of buildings significantly (SMOL et al., 2015), however its adoption in the built environment is still in its infancy (POMPONI; MONCASTER, 2017). To help further its adoption in the Construction Industry, the project BAMB (Building As Material Banks) was created in 2015 by the European Union and looks to help construction companies make the transition from the traditional linear system to the circular one (BAMB, 2016), focusing on the development of Building Material Passports and Reversible Buildings.

Since this concept has started being studied for the built environment, multiple research have been published with different focuses, given the complexity of the Construction Industry. The first article of this dissertation (Section 3) highlights the biggest research themes and their findings, as well as the research gaps still existing in this area.

5.2.2 Lean Construction

Lean Construction is a concept that has been derived from the automotive industry, when Taichii Ohno developed a production system based on the elimination of waste during the process, looking to become more efficient, agile and flexible (OHNO, 1997). This system became known as Toyota Production System, since it was in that company that was developed, and was created to face the tough economical period Japan was facing after losing the World War II, as it was different from the predominant system in the time created by Henry Ford, that aimed at creating standardized products, with high volumes and low production costs (OHNO, 1997).

This system was later named as Lean Production and inspired multiple studies to adapt its principles to other industries (WOMACK; JONES; ROOS, 1992). Inspired by this concept, the researchers James Womack and Daniel Jones studied it to apply in other industries, creating in the nineties the concept of Lean Thinking, that aimed at applying the concepts of Lean Production to any enterprise in the world, regardless of their field of work (WOMACK; JONES, 2004). This concept was based on five principles: (1) Specify value, as the value of the product depends on the perceived value from the ultimate customer; (2) Identify the value stream, that includes all the actions that add value to the product in the whole process; (3) Flow, that strives to make the value flow of a product continuous; (4) Pull, as the demand needs to be what is “pulling” the production; and (5) Pursue perfection, to always keep looking to improve the production process.

In the Construction Industry this concept became known as Lean Construction and it was first introduced by Koskela (1992) that looked to apply the principles developed in the Lean Production to the construction process. One of the biggest focus of the study of Koskela (1992) was to try to solve the problems existing in the conversion model that was predominant in the Construction Industry. In this model, there is no differentiation from conversion activities, the ones that add value to the product, from the flow activities, that do not add value (SHINGO, 1988).

In his report, Koskela (1992) created a series of 11 heuristic Lean Construction principles to apply the Lean Production concepts into the Construction Industry: (1) Reduce the share of non value-adding activities, to eliminate existing activities in the process that do not any value to the ultimate consumer or an internal client; (2) Increase output value through systematic consideration of customer requirements, as the value of the product is done regarding the value to the final client or an internal client; (3) Reduce variability, since more variability could mean more activities that do not add value to the product; (4) Reduce the cycle time, as with less time, most non value-adding activities are eliminated; (5) Simplify by minimizing the number of steps parts and linkages, as this principle can help reduce non value-adding activities and the complexity of the process, minimizing problems that might occur; (6) Increase output flexibility, as adding more flexibility without increasing costs will add more value to the final customer; (7) Increase process transparency, helping find the existing problems in the production; (8) Focus control on the complete process, instead of trying to improve only specific activities, in order to not lose sight of the full production process; (9) Build continuous improvement into the process, to always try to improve it; (10) Balance flow improvement with conversion improvement, as neither type of improvement can be overlooked or overimproved without considering the other; and (11) Benchmark, to mainly use successful cases of flow process from other industries.

5.3 RESEARCH METHODOLOGY

The conduction of this research was based on the question “What are the relations between the Circular Economy practices for the Construction Industry and the Lean Construction principles?” and to answer this question both concepts must be studied, and their interactions analyzed. However, this combination of concepts is something that has not been extensively studied - searching the terms “Circular Economy” and “Lean Construction” together in the title, abstract or keywords on the databases of Science Direct, Scopus and Web of Science resulted in a total of 1 paper - therefore is hard to find enough practical cases that can be analyzed to help answer the research question, showing the lack of research matching both concepts.

This situation shows the need to, first, study each concept separately and then correlate their principles to understand their interactions. This characterizes the research as qualitative (ROBSON, 2002) since the existing literature of both concepts will be analyzed and matched to reach the objectives.

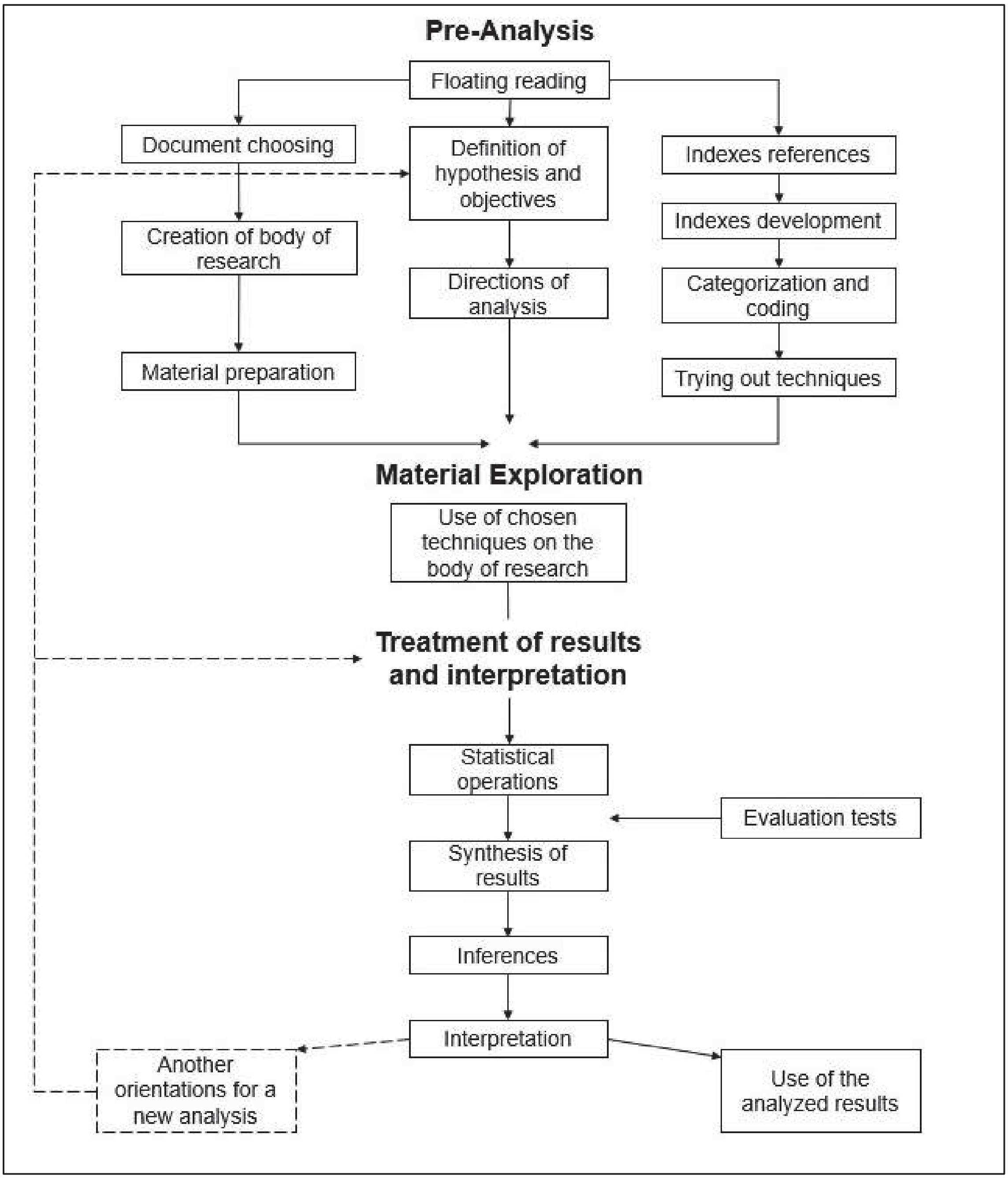
The concept of Lean Construction has been greatly studied in the academia – 2160 papers found when searching for the word “Lean Construction” in the databases of Science Direct, Scopus and Web of Science – and multiple studies have reported that the adoption of LC principles have resulted in an efficient process and reduced variability (FRANCIS; THOMAS, 2020).

In the other hand, the study of Circular Economy (CE) is still in its infancy (POMPONI; MONCASTER, 2017). To better comprehend the applications of this philosophy for the built environment, a systematic literature review was conducted in the Section 3 of this dissertation. The six biggest areas of research inside this theme were found and a list of CE practices, divided by their life cycle stage, for the Construction Industry was built based on the practices shown and discussed on the 45 articles included in that literature review.

With available qualitative information from both subjects of this research, there is the need to analyze them simultaneously, and for that the method of Content Analysis was chosen. Bardin (1977) defined this method as a group of communication analysis techniques aiming at obtaining, by way of systematical and objective procedures, indexes (quantitative or not) that allow the inference of knowledge concerning the conditions of production and reception of these messages.

This method follows a protocol of three different sequential phases. First, the pre-analysis, that is the stage responsible for organizing the research. Then, the material exploration follows, where all the gathered material for this research is analyzed. Finally, the treatment of obtained results occurs and an interpretation of them is given (BARDIN, 1977). FIGURE 1 shows all the steps of this method.

FIGURE 1 - PROTOCOL OF CONTENT ANALYSIS



SOURCE: Bardin (1977).

The organization of the research starts with the pre-analysis and is divided by five steps. The first is called floating reading, as it consists of making first contact with the subject and slowly this reading becomes more precise. After that comes choosing the material that will be included in the research, delimitating the body of research by databases, types of papers, timeframe or another factor that might influence the research.

The third step of the phase is the definition of hypothesis and objectives. This step is what characterizes what the research is going to be about, with the creation of hypothesis that the study is going to try to prove or disprove and the definition of the objective that it is going to be the goal of the research. The next step is the definition of indexes that will be used, as they have the role of proving or disproving the previous defined hypothesis. Finally, the chosen material of this study will be prepared for the analysis, by organizing the digital files, sorting out any physical documents and any other procedure that needs to be done prior to the analysis.

The next phase after the pre-analysis is doing the analysis of the prepared material. This phase will vastly vary depending on the objectives of each research, as each will need a technique that better suits it. Bardin (1977) defines six different types of analysis that can be done: (1) Categorical; (2) Evaluation; (3) Enunciation; (4) Expression; (5) Relationships; and (6) Speech.

After the analysis has been made, a treatment of all the results must occur to help interpret it. This treatment may start with statistical operations upon the obtained results and the use of validation tests may help accept or reject some of them. Afterwards, a synthesis of them must be made with also a selection of the results that better represent and help answer the defined objectives of the research. From there the authors can infer and better interpret the results of this content analysis. TABLE 1 shows the sequence of steps taken in this research.

TABLE 1 - SEQUENCE OF STEPS OF THIS RESEARCH

Steps	Adopted strategy
Pre-Analysis	
Floating Reading	Reading of material inside the topics of Circular Economy, Lean Production, Lean Thinking and Lean Construction
Document Choosing	Focus on peer reviewed or conference papers that focused on the topics of Circular Economy for the Construction Industry and Lean Construction
Definition of hypothesis and objectives	Finding the correlation between the Circular Economy practices focused on the Construction Industry with the Lean Construction principles
Material preparation	Use of the table developed in Section 4 of this dissertation with the Circular Economy practices in combination of Koskela (1992) principles of Lean Construction
Material Exploration	

Use of techniques of Content Analysis	Creation of a relationships matrix between Circular Economy practices and Lean Construction principles, based on the relationship analysis of Bardin (1977)
Treatment of results and interpretation	
Statistical operations	Use of Excel to compile the statistical results
Synthesis of results	List of all the relationships between the Circular Economy practices and Lean Construction principles and their explanation
Inferences	Discussion of the obtained results
Interpretation	Possible conclusions from the obtained results and discussion

SOURCE: The authors (2020).

For this research, the objective involved the Circular Economy practices that are focused on the Construction Industry and the Lean Construction principles, therefore the first step of the content analysis contemplated a floating reading of all related subjects, including Circular Economy in general, Circular Economy for the built environment, Lean Production, Lean Thinking and Lean Construction. After obtaining a better understanding of both subjects, the chosen documents for this study focused on peer reviewed or conference papers that had their focus on Circular Economy for the Construction Industry or Lean Construction.

With the delimitation of the material that would be used on this research, the next step was defining the hypothesis and objectives of this study. Since this research was looking to find the relationships between two concepts, there was no need to define hypothesis that the study would be based around. Therefore, the definition of the objective was to “find the interactions, positive or not, between the Circular Economy practices and the Lean Construction principles”.

The final step of the pre-analysis was the material of preparation that would be used on this analysis. The first part of the material needed to be a list of practices that uses Circular Economy concepts on the built environment. This list was created on Section 4 of this dissertation and divided the practices in their predominant life cycle stage. The second part was the selection of Lean Construction principles to correlate with the Circular Economy practices. These principles were selected from Koskela (1992), where he develops 11 heuristic principles based on the Lean Production concept of Ohno (1997) focused on the Construction Industry.

After the pre-analysis, the material exploration follows. Bardin (1977) lists six different content analysis techniques, and the one that fits the most what this research is trying to accomplish was the relationship analysis. This type of technique tries to find the relations between two or more elements in the same context and uses a matrix to find their interactions (BARDIN, 1977).

This same type of strategy has already been used in the Construction Industry by Sacks et al. (2010) when trying to find the interactions between Lean Construction and Building Information Modeling (BIM).

To create this relationships matrix, the list of Circular Economy practices developed by the first article of this dissertation was used and is listed on TABLE 2, divided by their predominant life cycle stage and their respective row key in the matrix.

TABLE 2 - CIRCULAR ECONOMY PRACTICES FOR THE CONSTRUCTION INDUSTRY

Life cycle stage	Circular Economy practices	Row key
Building Design	Design and use of modular buildings	1
	Design for adaptability of existing buildings	2
	Design for Disassembly of building structures	3
	Use of a scale to analyze the level of implementation of Circular Economy practices in the company	4
	Use of a simulation in a BIM model to analyze the reuse potential of the materials of different types of designs early in the project.	5
	Use of Life-cycle analysis to find the benefits of reusing different types of materials in the design stage	6
	Use of material stock data to help reuse of materials of a new building	7
Manufacture	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building	8
	Development of material passports	9
	Reuse of secondary materials in the production of building materials	10
Construction	Reuse of building materials in a new construction	11
	Waste reduction	12
	Off-site construction	13
Operation	Use of a tool to evaluate the state of materials during the lifespan and end of life of a building	14
	Use of water management practices	15
	Minimize recuperative maintenance with preventive maintenance	16
End of Life	Analyze the potential for reuse or recycling of existing materials and if it is feasible comparing to using new materials.	17

	Management of demolition waste	18
	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment	19
	Deconstruction of building structures and parts	20

SOURCE: The authors (2020).

Similarly, the list of Lean Construction principles developed by Koskela (1992) is listed on TABLE 3 with their respective column key for the matrix.

TABLE 3 - LEAN CONSTRUCTION PRINCIPLES

Lean Construction principle	**Column key**
Reduce the share of non value-adding activities	A
Reduce the cycle time	B
Reduce variability	C
Simplify by minimizing the number of steps, parts and linkages	D
Increase output flexibility	E
Increase process transparency	F
Increase output value through systematic consideration of customer requirements	G
Focus control on the complete process	H
Build continuous improvement into the process	I
Balance flow improvement with conversion improvement	J
Benchmark	K

SOURCE: Adapted from Koskela (1992).

The next section of this research shows the development of the matrix of correlations between the studied concepts and an explanation of all chosen interactions, along with different statistical results obtained from the developed matrix.

5.4 RESULTS

This section is divided in two parts. First, the created matrix of relationships is shown, along with all the found interactions. Following, a series of statistical analysis are drawn from the obtained results.

5.4.1 Relationships matrix

The next step in this research was creating the relationships matrix between both subjects of this study. The Circular Economy practices were listed in the rows and the Lean Construction principles in the columns, then each practice was compared to each principle and interactions were drawn, inferred from the reasoning of the authors based on the explanation of each practice obtained from the literature review conducted in the Section 3 of this dissertation and the authors understanding of each of the Lean Construction principles from the literature. The matrix is shown at TABLE 4.

This matrix was used to compare both subjects and draw not only the positive interactions, but also the negative interactions. These were the interactions in which the Circular Economy practice had something counterproductive with the objective of the Lean Construction principle. The positive interactions were pointed using positive numbers, and the negative interactions were given by the numbers inside the brackets.

At APPENDIX 1, each interaction is explained. It is important to note that these interactions were drawn based on studies that had Circular Economy practices for the Construction Industry as their focus, and did not use or compare any of them to any Lean Construction principle or concept, therefore all found interactions are theorical and may need further study to prove or disprove them.

To help understand the results found in this relationships matrix, a distance-based network was created in the software VOS Viewer. This network shows the connection between nodes, in which the bigger the node, the bigger is the amount of citations a certain word or phrase has. The correlation between the words is also shown from the distance between nodes, in which with bigger correlation, the nodes are closer (VAN ECK; WALTMAN, 2014).

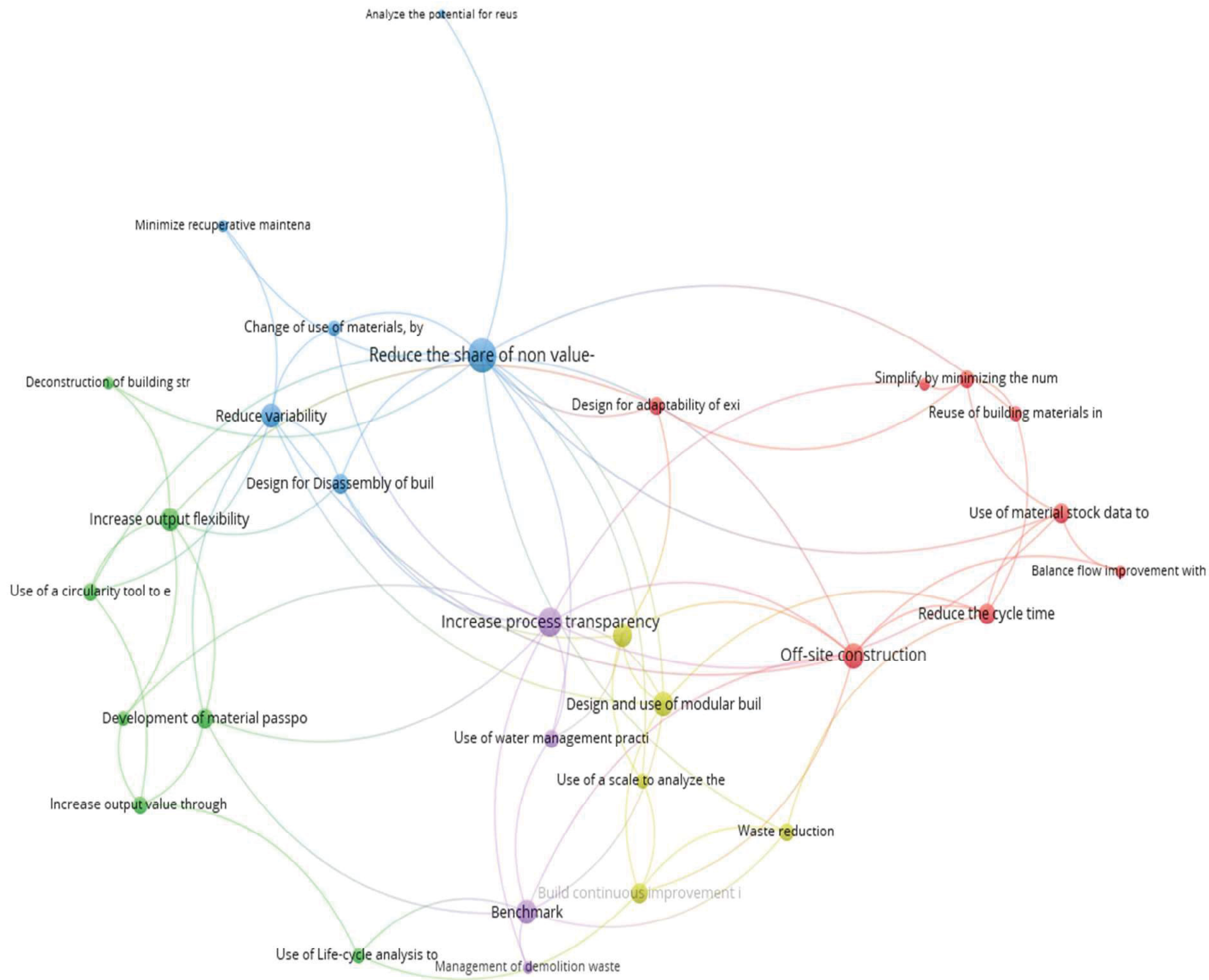
In the case of this relationships matrix, a network was created based on the positive interactions found in the content analysis, dividing the CE practices and the LC principles, and is shown at FIGURE 2. This network divides the interactions in five distinct areas, by color of the nodes, in which the interactions were more similar to each other. The biggest LC principles of each of these areas were “Reduce the share of non value-adding activities”, “Increase output flexibility”, “Build continuous improvement”, “Reduce the cycle time” and “Increase process transparency”.

TABLE 4 – RELATIONSHIPS MATRIX BETWEEN CIRCULAR ECONOMY PRACTICES AND LEAN CONSTRUCTION PRINCIPLES

Life Cycle Stage	Circular Economy Practices	Lean Construction Principles										
		Reduce the share of non value-adding activities	Reduce the cycle time	Reduce variability	Simplify by minimizing the number of steps, parts and linkages	Increase output flexibility	Increase process transparency	Increase output value through systematic consideration of customer requirements	Focus control on the complete process	Build continuous improvement into the process	Balance flow improvement with conversion improvement	Benchmark
		A	B	C	D	E	F	G	H	I	J	K
Building Design	1	1	2	3			4		5	6		7
	2	8			9	10			11			
	3	12		13	(71)	14	15		16			
	4	17							18	19		
	5					20	21	22				
	6							23		24		25
	7	26	27		28		29				30	
Manufacture	8	31		32			33	(72)				
	9			34		35	36	37				38
	10											
Construction	11	39	40		41							
	12	42	43							44		45
	13	46	47	48	(73)		49		50	51	52	53
Operation	14				54		55					
	15	56					57		58			59
	16	60		61								
End of Life	17	62										
	18						63					64
	19	65		66		67		68				
	20	69			(74)	70						

SOURCE: The authors (2020).

FIGURE 2 - DISTANCE-BASED NETWORK FROM THE INTERACTIONS BETWEEN CE PRACTICES AND LC PRINCIPLES

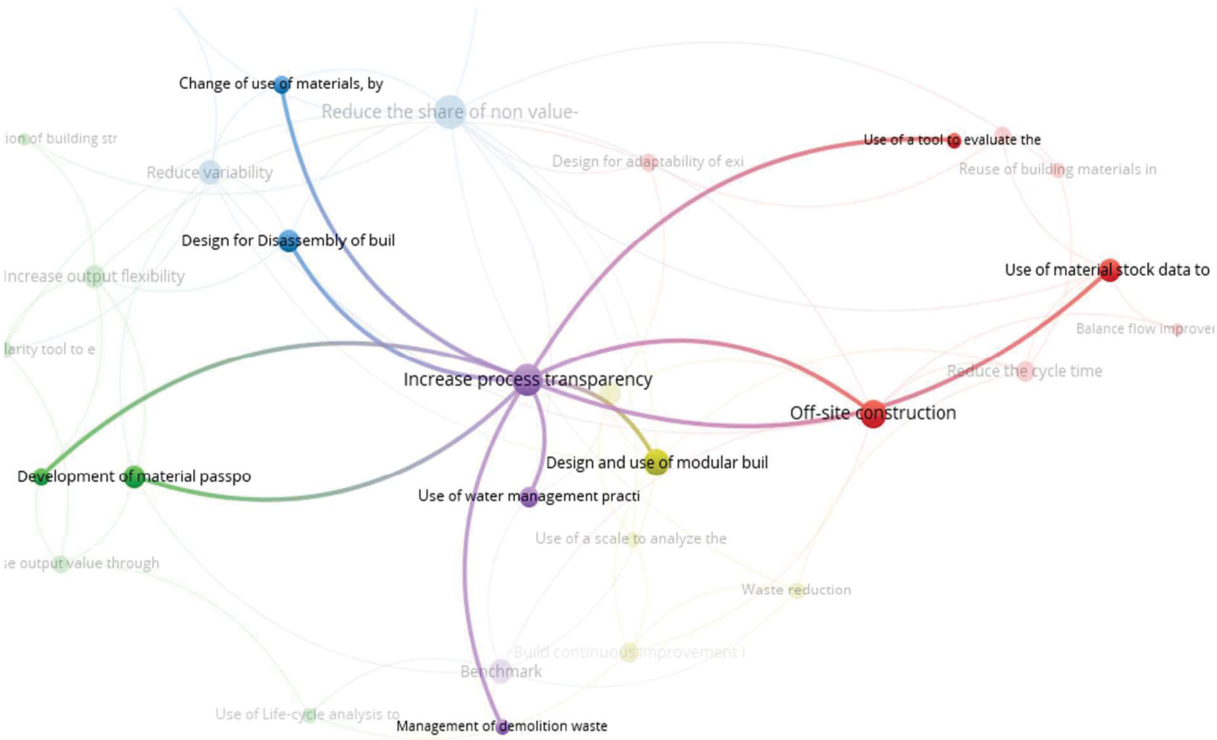


SOURCE: The authors (2020).

The size of the nodes and their connections correlates to the amount of interactions found and will be discussed further in the section 5.5 of this paper. Outside of that, the biggest result that can be extracted from this network is from the area that was in the middle of the network, in the purple color.

This area is headlined by the LC principle “Increase process transparency” and shows that this principle has the most varied interactions with CE practices in all five of the divided areas, as shown by the FIGURE 3, that zooms in the connections of this principle in the network. This result is an indication that, although this LC principle did not have the biggest amount of interactions, is the one that is most present in the different types of CE practices, not only in the similar practices.

FIGURE 3 - NETWORK INTERACTIONS AROUND THE LC PRINCIPLE "INCREASE PROCESS TRANSPARENCY"



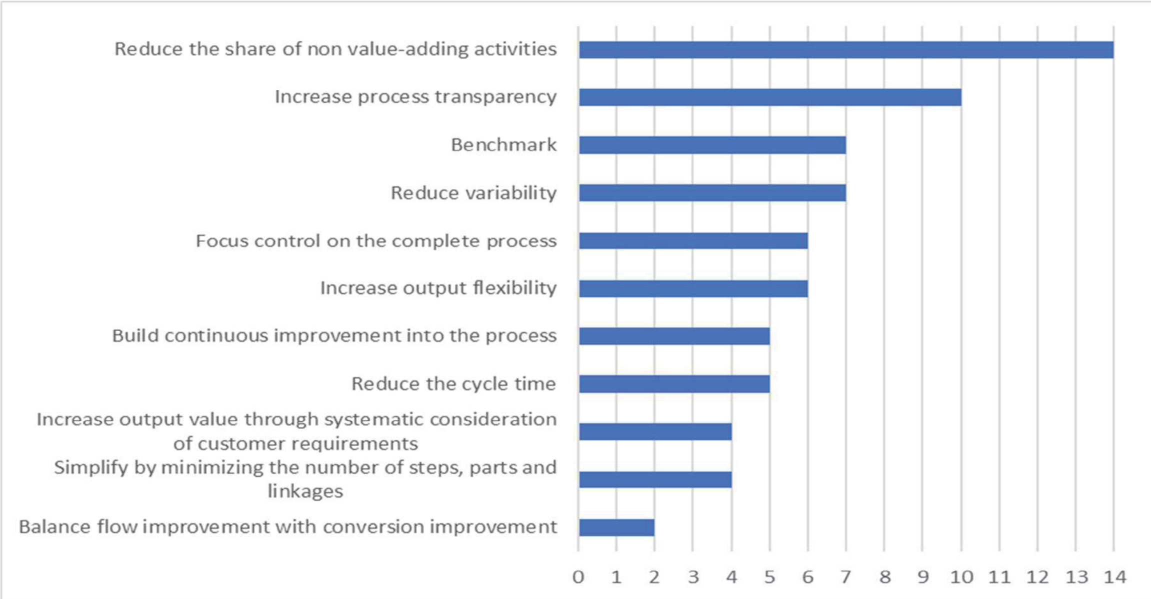
SOURCE: The authors (2020).

5.4.2 Statistical results

From the created matrix it is possible to obtain a series of results to help understand the relationship between the studied subjects. First, FIGURE 4 shows the Lean Construction principles that had the most positive correlations between the Circular Economy practices.

The principle that had most interactions was “reduce share of non value-adding activities” with 14 positive interactions (70% of all practices). This principle was followed by “increase process transparency” with 10 positive interactions and “benchmark” and “reduce variability” with 7 positive interactions each. The principle that had the least positive interactions was “balance flow improvement with conversion improvement” with only 2 positive interactions, followed by “increase output value through systematic consideration of customer requirements” with 4 positive interactions.

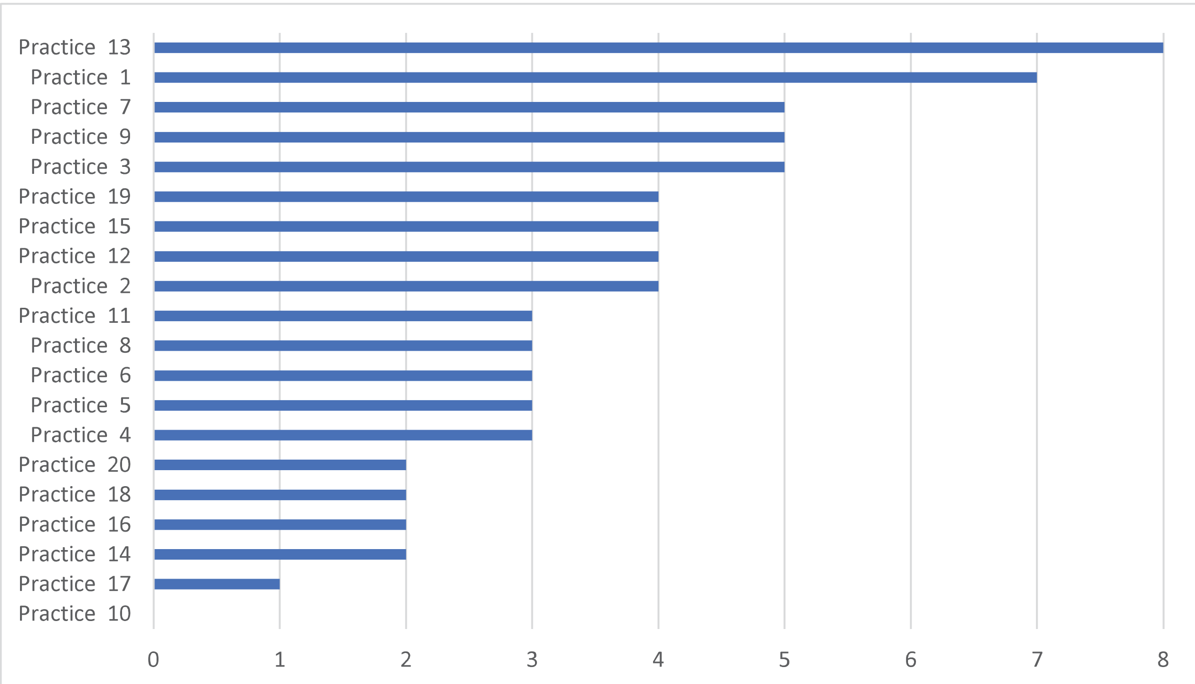
FIGURE 4 - INTERACTIONS PER LEAN CONSTRUCTION PRINCIPLE



SOURCE: The authors (2020).

Another possible analysis was the inverse of FIGURE 4, considering the Circular Economy practices that had the most Lean Construction principles in their concept. This is shown in FIGURE 5.

FIGURE 5 - INTERACTION PER CIRCULAR ECONOMY PRACTICE



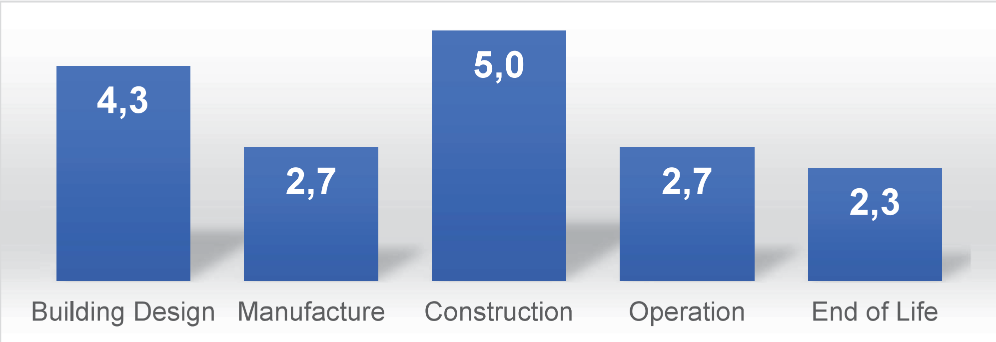
SOURCE: The authors (2020).

The practice with most positive interactions was "off-site construction", with 8 principles (72,7% of all principles). Following that, "design and use of modular buildings" had 7 positive interactions.

The practice that had the least positive interactions with LC principles was "reuse of secondary materials in the production of building materials" without any positive interaction. The practice "analyze the potential for reuse or recycling of existing materials and if it is feasible comparing to using new materials" had only 1 positive interaction, and other five practices had only 2 positive interactions.

The last analysis drawn from the created matrix is related to the life cycle stage that each practice is inserted. FIGURE 6 shows the average number of positive interactions that the circular practices had in their life cycle stages.

FIGURE 6 - AVERAGE NUMBER OF POSITIVE INTERACTIONS PER STAGE



SOURCE: The authors (2020).

The stage that had the biggest average was Construction, averaging 5 positive interaction per practice, followed by Building Design with 4,3. The phases that averaged the least number of positive interactions was End of Life, with 2,3, followed by Manufacture and Operation, with 2,7 interactions each.

5.5 DISCUSSION

Analyzing the created matrix in TABLE 4 and the obtained results from section 4.2 it is possible to interpret what those results mean for the relationships between CE practices and LC principles. First, FIGURE 4 shows the LC principles that had the most number of positive interactions with CE practices, with "reduce the share of non value-adding activities" having interactions with 14 out 20 CE practices. This happens mostly because the basis of the concept of Circular Economy is to change the linear approach of “take, make, dispose” that dominates the Construction Industry into a better management of resources at the end of life stage of a building, reusing, recycling or deconstructing structures and materials rather than dispose them (EMF, 2015; POMPONI; MONCASTER, 2017). This proposed change makes so that the phase of demolition and disposing of materials is reduced, therefore reducing an activity in the life cycle that does not add value to the building, at the same time as it keeps the materials in the industry, adding more value to the building. TABLE 5 shows and explains each interaction found with the 14 CE practices.

TABLE 5 - ALL CE PRACTICES INTERACTIONS WITH THE LC PRINCIPLE "REDUCE THE SHARE OF NON VALUE-ADDING ACTIVITIES"

Matrix Number	Interaction	EC Practice
1	The use of modular buildings and structures enables the use of prefabrication off-site, with better control of the process, that can help eliminate phases of the construction that does not add value to the final product.	Design and use of modular buildings
8	With a design that considers the adaptability of buildings in its life cycle phases that don't add value to the final products can be eliminated. The process of refurbishing of buildings that do not consider adaptability in its design is likely to have more steps and take more time than one that did consider it.	Design for adaptability of existing buildings
12	When a building structure is designed with the possibility of being assembled and latter disassembled for a different use, its lifespan can be prolonged, eliminating its early demolition that would end the value of the structure, therefore it eliminates a step that does not add value to the product.	Design for Disassembly of building structures
17	Using a scale to analyze the level of implementation of Circular Economy practices in the company can help minimize the steps of the process that won't add value to the final process, since there will be a better understanding of how much the company is using the concepts and how it can improve.	Use of a scale to analyze the level of implementation of Circular Economy practices in the company
26	The creation and use of material stocks for reuse have the potential to impact how the construction supply chain works, eliminating the steps of producing new materials, since the used materials on the stock will be reused, therefore eliminating steps on the cycle.	Use of material stock data to help reuse of materials of a new building
31	Giving the ownership of building structures to the manufacturer will make those materials cheaper, since the manufacturer can reuse them later. This helps in the way of reducing the step of buying the materials, because for the client it doesn't matter if the materials will be reused or become waste, so this step removes a non-value step of the construction process.	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building

39	The demolition phase of a building is a step that does not add value to the final product, as is just a way to dispose the building materials at his end of life. In this way, reusing those materials will eliminate this demolition step and reintroduce these materials into the supply chain of construction, adding more value to buildings.	Reuse of building materials in a new construction
42	Elimination of waste in the production is one of the biggest goals of the Lean Thinking, since is an activity that does not add value to the final product, therefore waste reduction in the construction has the same principles.	Waste reduction
46	Producing parts of a building structure off-site allows the possibility of having a better control of the process, better planning and layout of the production site, eliminating tasks that could exist in the construction site, reducing transporting activities in the production and other activities that would not add value to the product.	Off-site construction
56	The use of water management practices to keep the water in the building for more time decreases the amount of natural water the building will use during its operation phase, reducing the step of receiving more potable water.	Use of water management practices
60	Controlling the structures and materials of a building during the operation phase allows the possibility to minimize the need for recuperative maintenance, by using preventive maintenance, which usually is cheaper, faster and easier. By reducing the use of recuperative maintenance, it reduces a activity that does not add value to the building.	Minimize recuperative maintenance with preventive maintenance
62	This practice is essential for the circularity of buildings in their end of life stage, to find which materials or structures can be reused or recycled, postponing the step of disposing them, an activity that will end their value to the building.	Analyze the potential for reuse or recycling of existing materials and if it is feasible comparing to using new materials.
65	The use of a circularity tool in the end of life stage of a building gives another dimension to the Circular Economy concept, instead of trying to reuse or recycle the materials that would be disposed, it tries to readapt the whole building so that their materials and structures can be used for a longer time, eliminating the step of disposing them in a time that would not be needed.	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment
69	The use of this practice becomes much easier with the use of Design for Disassembly at the building design phase, but even without that it can help reduce the amount of structures that are totally disposed in end of life stage, reducing this non value activity.	Deconstruction of building structures and parts

SOURCE: The authors (2020).

The other LC principle that had the second most positive interactions was “increase process transparency”, with half of CE practices drawing interactions. The reasoning behind this comes from the fact that CE projects are designed to better manage its resources at its end of life stage, therefore they usually have a predefined use for materials or structures at the later stage, mapping the whole process and making it more transparent to control it.

In other hand, the LC principle that had the least positive interactions was "balance flow improvement with conversion improvement" with only 2. This is a principle that focus on the improvement of the process, to better manage the resources used to improve balance flow (usually more impactful but requires longer time to improve) with conversion flow (KOSKELA, 1992). With this focus on managing the improvement of the process, only the CE practices of "use of material stock data to help reuse of materials of a new building" and "off-site construction" consider this principle. The first practice focuses on managing the information flow and conversion of used materials to be reused on new buildings, and the second must manage both improvements since the production of structures happens similarly as the conventional industry.

Given the results from FIGURE 5 it is possible to analyze the previous results from another point of view, considering the CE practices that had more interactions with LC principles. The practice that had the greatest number of positive interactions was "off-site construction", with 8 positive interactions and 1 negative interaction. This happens because prefabricated buildings are different from conventional constructions, since they are manufactured off-site in a more controlled way (KYRÖ; JYLHÄ; PELTOKORPI, 2019).

This makes this the whole process much more like the manufacture industry than the Construction Industry, therefore the concepts of Lean Production can be better adopted there (MINUNNO et al., 2018), bringing benefits like better quality control, resource efficiency and less disruption in the construction phase (JAILLON; POON, 2010). TABLE 6 explains the interactions found with each Lean Construction principles. Similarly, the CE practice that had the second most number of positive interactions, with 7, was "design and use of modular buildings", since is a practice that takes advantage of off-site construction and incorporates most of its principles in it.

TABLE 6 - ALL LC PRINCIPLES INTERACTIONS WITH THE CE PRACTICE "OFF-SITE CONSTRUCTION"

Matrix Number	Interaction	LC Principle
46	Producing parts of a building structure off-site allows the possibility of having a better control of the process, better planning and layout of the production site, eliminating tasks that could exist in the construction site, reducing transporting activities in the production and other activities that would not add value to the product.	Reduce the share of non value-adding activities

47	With better control of the production process, the steps can be optimized to reduce the cycle time of producing a structure, something that is much harder to achieve in a construction site, given the bigger number of variables that can interfere with the production.	Reduce the cycle time
48	Off-site production has less variables and possible interferences to the production than on the construction site, due to the controlled environment, therefore reducing the variability of the product.	Reduce variability
49	The off-site production allows a better control of the full process, therefore all the steps must be defined earlier as they become more clear, improving the transparency of the construction.	Increase process transparency
50	Moving the production of building structures and parts to an off-site location reduces the number of involved variances in the construction, allowing the company to better map and control the whole process.	Focus control on the complete process
51	With a more standardized process flow in the production, the off-site construction gives the possibility to build continuous improvement easier than it is on the traditional construction site, since the off-site construction site will not change to much from one project to another.	Build continuous improvement into the process
52	This practice happens in a more controlled environment, in which the information flow between processes becomes as important as it is the conversion between them, therefore it demands a balance between flow improvement and conversion improvement.	Balance flow improvement with conversion improvement
53	The off-site construction is a practice that is based on the production process of other industries, like the manufacture or automotive, therefore it can easily look to replicate the successful cases of these other industries into the construction.	Benchmark

SOURCE: The authors (2020).

In the other specter of this analysis, the CE practice “reuse of secondary materials in the production of building materials” did not have any positive interaction with the LC principles. This practice considers the phase of manufacture of building materials, replacing the usual raw materials with secondary materials, that have already been used and been recycled or reprocessed, making it as a practice that does not change the process of designing or constructing a building, therefore not likely to have any interactions with the LC principles.

Other than this practice, “analyze the potential for reuse or recycling of materials and if it is feasible comparing to using new materials” only had 1 positive interaction with “reduce the share of non value-adding activities”, since it is a practice that can reduce the amount of materials disposed in end of life stage, therefore eliminating a step that does not add value to the building, but is only a strategy to analyze materials in the final stage of the building, leaving not much room to incorporate any of the other principles.

Analyzing the results from a more global point of view, FIGURE 6 gives the average number of positive interactions for each life cycle stage that their practices had. The phase that averaged the biggest number was the Construction, with 5. This should be expected since this stage is where the final product of the Construction Industry is created, being the step in which the building structures and parts are assembled and resembles the most a line of production, the place where the concept of Lean Production was stablished.

With most of the LC principles focusing in the production part of the life cycle, this stage has the most impactful practices that incorporates those principles, like "off-site construction" that had the greatest number of positive interactions or "waste reduction" as it is one of the biggest objectives of implementing the Lean concept in any type of industry.

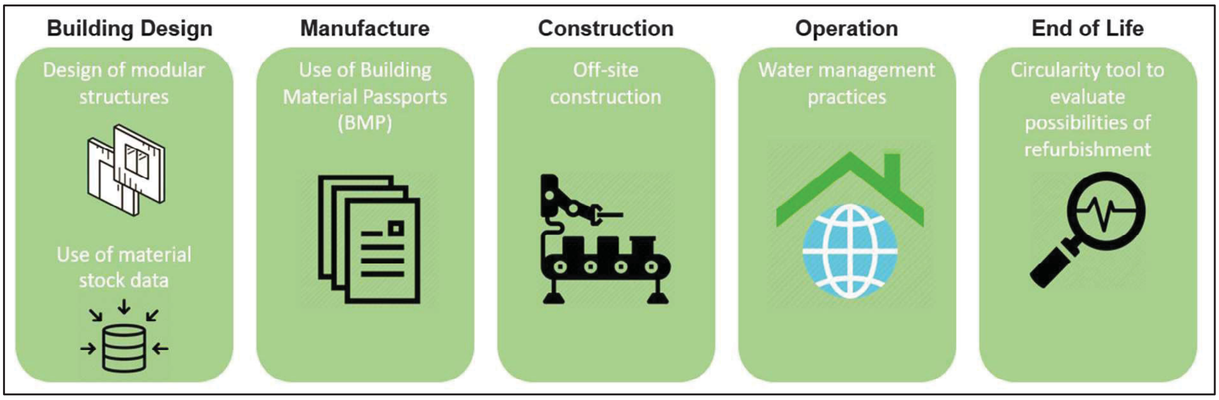
Following closely the Construction stage, the phase of Building Design averages 4,3 positive interactions per practice. This happens because this stage gives the possibility to better manage all life cycle stages before starting a construction. In the design phase it is possible to use BIM tools or LCA to choose materials that will give a better rate of reusability, design structures to be deconstructed and reused at end of life stage, all practices that improve the management of all phases of a building, a core element of Circular Economy, that also is present in the concept of Lean Construction.

The other three life cycle stages had very similar averages of positive interactions, with a difference of only 0,4 percentage points between them, with their collective average of 2,5. This shows that all life cycle stages, outside of the Construction and Building Design, have some LC principles incorporated into them, but are not the main focus of this philosophy. They all have practices that are closer to the concept of Lean Construction, but ultimately, they do not have a bigger presence of LC principles as the two other life cycle stages.

Even though these last three phases lack interactions with LC principles, they all have practices that get close to the average number of positive interactions of the Construction stage, making it possible to describe an optimal way of applying Circular Economy in a building that also incorporates the concepts of Lean Construction.

FIGURE 7 shows the CE practices of that had the biggest number positive interactions inside their own life cycle stage. In the Building Design phase there are multiple practices that incorporates a considerable number of LC principles, and the use of one does not eliminate the possibility of using another one to help the circularity of the project. Therefore, an optimal project sequence that incorporates CE and LC should make use of the design of modular structures since they allow a better management of the production, helping eliminate waste and activities that will not add value to the final product. Also, in the Building Design phase, it is recommended that material stock data available is used to help find existing building materials in the area of the project that can be reused for the building.

FIGURE 7 - OPTIMAL PROJECT SEQUENCE INCORPORATING CIRCULAR ECONOMY AND LEAN CONSTRUCTION CONCEPTS



SOURCE: The authors (2020).

To help the choosing of better materials in the Building Design phase, the development of Building Material Passports (BMP) must be improved in the Manufacture phase. This tool has the potential of giving more accurate data and information to decision makers in the design phase, allowing them to better manage the resources in the full life cycle of the building.

In the Construction stage the most recommended practice is the use of off-site construction, as it is enabled in this optimal project by the design of modular structures. This practice had the most number of positive interactions of all CE practices, since an off-site construction is very similar to the manufacture industry and it is easier to apply the concepts of Lean Production, at the same time it helps the goals of better management of resources and reducing waste from the concept of Circular Economy.

The following stage, the Operation, is the hardest for the construction company responsible for the building construction to have control, since the building may have different owners and, usually, after completion of the construction the companies will leave the management of the building for people that might not be in the Construction

Industry, making it hard to use practices that help the circularity of the full project. This can be helped when the design foresees water management practices in the project, such as green roof or rainwater harvesting, that can be operated by the owners of the building without much problems and will help the circularity of the water in the project.

In the later stage of the project, the practice that has the biggest impact in this optimal project is the use of a circularity tool to evaluate the building and find the best solutions to refurbishment, such as the developed by Bertino et al. (2019), helping extend the life of the building and delay the disposing of materials existing in the building.

Through the use of these described practices it is expected that this building should be considered a Reversible Building, since it considers all life cycle stages in the design phase, looking to reduce the amount of waste generated by finding ways of reusing the structures and materials. It also uses BMP to consider the reuse potential of the chosen materials earlier in the process and takes advantage of a tool to analyze the refurbishment options in the final stage, which is helped by the fact that modular structures were used in the construction. With these practices, this project sequence fits into the description of a Reversible Building Design from BAMB (2018), in which a design should consider all life cycle phases of a building and guarantee a high reuse potential of its systems, products and materials, in the same time it has a high transformation potential.

This optimal project sequence has adopted the most impactful practices that seek the Circular Economy and consider Lean Construction principles, but it is only a theorical combination of different practices that have to be tested in a real project to find if they achieve the goals they aim at. At the same way, this project considers only one or two practices per life cycle stage, but in reality, a Circular Economy can adopt more practices to help its goal, and these additional combinations might also need real life project testing.

5.6 CONCLUSIONS

Looking to answer the question of “what are the correlations between Circular Economy practices and Lean Construction principles”, this research made use of a content analysis technique to find the interactions between the CE practices listed by the first article of this dissertation and the LC principles of Koskela (1992). A relationship analysis was used to create a matrix of relationships between both subjects, finding both positive and negative interactions. In total 70 positive interactions were found, as well as 4 negative interactions.

Analyzing the LC principles that had more interactions with the CE practices, the principle “reduce the share of non value-adding activities” had positive interactions with 14 out of the 20 listed CE practices, since it is a consequence of one the objectives of Circular Economy, the reuse of materials. This practice seeks the elimination of the phase of disposing them, that does not add value to the final product. Other than that, the LC principle “Increase process transparency” was found to be the principle that had interactions with the most varied CE practices after creating a distance-based network from the positive interactions.

In the other direction, the CE practices that had more interactions with the LC principles were also analyzed. The practice of “off-site construction” had 8 positive interactions due to the similarity to the manufacture industry. This practice allows a better management of the production, making it easier to implement the concepts of Lean Production, therefore having a considerable number of positive interactions with the LC principles.

The practice of “off-site construction” having the most number of positive interactions comes to the agreement of the fact that the Construction stage of a building is the life cycle phase that had the highest average of positive interactions, followed closely by the Building Design phase. Although the other three life cycle stages had smaller averages, it was possible to create an optimal project sequence that incorporates multiple CE practices at the same time as it gets closer to the Lean Construction concept.

This optimal project sequence is a theorical representation of a project for the Construction Industry that seeks the objectives of Circular Economy, through the use of a Reversible Building Design, and takes advantage of the Lean Construction principles. Even though this project might need further testing in a real environment to prove these results, it shows that it may be possible to utilize both concepts of Circular Economy and Lean Construction together in the built environment.

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APPENDIX 1 – EXPLANATION OF EACH FOUND INTERACTION

Matrix Number	Interaction	EC Practice	LC Principle
1	The use of modular buildings and structures enables the use of prefabrication off-site, with better control of the process, that can help eliminate phases of the construction that does not add value to the final product.	Design and use of modular buildings	Reduce the share of non value-adding activities
2	Since modular buildings have usually an off-site construction, the process can be better controlled, and the time of production can be smaller comparing to on-site construction of the same type of structures.	Design and use of modular buildings	Reduce the cycle time
3	With a better control of the production of modular buildings, the variability can be reduced if compared to on-site constructions.	Design and use of modular buildings	Reduce variability
4	The off-site construction can have a better transparency of the steps necessary and taken in the construction phase, helping mitigate and eliminate the steps that don't aggregate value to the final product.	Design and use of modular buildings	Increase process transparency

5	The control of the full process of prefabrication of modular buildings can help architects and engineers have a better view and control of the full construction stage.	Design and use of modular buildings	Focus control on the complete process
6	With well-designed stages of production of modular buildings, it is easier to introduce a continuous improvement.	Design and use of modular buildings	Build continuous improvement into the process
7	The use of off-site construction is much newer to the Construction Industry than to other types of industries like manufacturing and mechanical, therefore there are a lot of opportunities to use successful strategies of those industries in off-site construction than in on-site.	Design and use of modular buildings	Benchmark
8	With a design that considers the adaptability of buildings in its life cycle phases that don't add value to the final products can be eliminated. The process of refurbishing of buildings that do not consider adaptability in its design is likely to have more steps and take more time than one that did consider it.	Design for adaptability of existing buildings	Reduce the share of non value-adding activities
9	The process of adapting a building that was designed for adaptability will be simpler than one that did not design it, decreasing the number of necessary steps and changes to adapt the building to a new use.	Design for adaptability of existing buildings	Simplify by minimizing the number of steps, parts and linkages
10	The concept of designing a building with possibilities to adapt it for a different use latter in its life cycle has an intrinsic flexibility that buildings that don't use this concept will not have.	Design for adaptability of existing buildings	Increase output flexibility
11	Designing a building with characteristics that allows it to have a different use than the initial one can help the architects and engineers that designed it to have a bigger control of the stages of the life cycle of the building, making it better prepared to the changes that might occur.	Design for adaptability of existing buildings	Focus control on the complete process
12	When a building structure is designed with the possibility of being assembled and latter disassembled for a different use, its lifespan can be prolonged, eliminating its early demolition that would end the value of the structure, therefore it eliminates a step that does not add value to the product.	Design for Disassembly of building structures	Reduce the share of non value-adding activities
13	The design of structures that can be disassembled reduces the variability of trying to disassemble and reutilize a structure that has not been designed with this concept in the beginning, reducing waste and maximizing the reuse potential of building materials and structures.	Design for Disassembly of building structures	Reduce variability
14	A building structure designed for disassembly will have more flexibility to the end user as it can be reused in more ways in the end of life of the building.	Design for Disassembly of building structures	Increase output flexibility
15	With more information about the structures at end of life of buildings the whole process gains better transparency, since the steps to reuse them are better defined and clearer.	Design for Disassembly of building structures	Increase process transparency
16	With better defined steps to reuse materials and structures at end of life, the whole process gets better control.	Design for Disassembly of building structures	Focus control on the complete process

17	Using a scale to analyze the level of implementation of Circular Economy practices in the company can help minimize the steps of the process that won't add value to the final process, since there will be a better understanding of how much the company is using the concepts and how it can improve.	Use of a scale to analyze the level of implementation of Circular Economy practices in the company	Reduce the share of non value-adding activities
18	The use of this scale to understand how well the construction company is using the Circular Economy practices can help them have a better view of the bigger picture of the full process, instead of focusing on separate tasks.	Use of a scale to analyze the level of implementation of Circular Economy practices in the company	Focus control on the complete process
19	With a quantitative index that gives qualitative results, it becomes easier for the company to build continuous improvement, since this scale can be applied at the end of each project to find if the company is improving in utilizing Circular Economy concepts and practices.	Use of a scale to analyze the level of implementation of Circular Economy practices in the company	Build continuous improvement into the process
20	Using simulation tools earlier in the building design can increase the flexibility to reuse the materials and structures at end of life of the building, as it gives the results of which material has better potential to be reused or recycled, therefore increasing the flexibility of these materials.	Use of a simulation in a BIM model to analyze the reuse potential of the materials of different types of designs early in the project	Increase output flexibility
21	After using simulation tools to find which material is better suited, considering the reuse potential, the process becomes more transparent, since it will be known the estimative of how much of a material or structured it can be reused, instead of only analyzing this potential at the end of life stage.	Use of a simulation in a BIM model to analyze the reuse potential of the materials of different types of designs early in the project	Increase process transparency
22	This practice gives the potential of using client considerations early in the building design, since it brings results of different types of materials and their reuse potentials, making it easier to consult the clients requirements and opinions to improve the product quality.	Use of a simulation in a BIM model to analyze the reuse potential of the materials of different types of designs early in the project	Increase output value through systematic consideration of customer requirements
23	Using Life cycle analysis in the building design phase gives the company the opportunity to show the results of embodied energy and carbon to their clients, allowing them to help choosing between materials to improve the quality expected by the clients.	Use of Life-cycle analysis to find the benefits of reusing different types of materials in the design stage	Increase output value through systematic consideration of customer requirements
24	The use of a LCA in a project allows the company to compare the results between projects and always try to find other materials that give better results and keep improving in this regard.	Use of Life-cycle analysis to find the benefits of reusing different types of materials	Build continuous improvement into the process

		in the design stage	
25	Life cycle analysis is an established tool already used in other types of industries, giving the opportunity for construction companies to use successful examples of other areas to apply in their building designs and obtain better results.	Use of Life-cycle analysis to find the benefits of reusing different types of materials in the design stage	Benchmark
26	The creation and use of material stocks for reuse have the potential to impact how the construction supply chain works, eliminating the steps of producing new materials, since the used materials on the stock will be reused, therefore eliminating steps on the cycle.	Use of material stock data to help reuse of materials of a new building	Reduce the share of non value-adding activities
27	While using available material stock data, it is possible to find existing material in buildings that can be reused and therefore will be reduce the time necessary to manufacture the material, reducing the overall cycle time of production.	Use of material stock data to help reuse of materials of a new building	Reduce the cycle time
28	When using existing material stocks, the steps of producing new materials will be decreased, therefore eliminating this step in various new buildings.	Use of material stock data to help reuse of materials of a new building	Simplify by minimizing the number of steps, parts and linkages
29	By having the material stock data of buildings, the process transparency is improved since the data of existing buildings is available and the process of choosing the materials of a new construction becomes more transparent as well as the circularity of the project.	Use of material stock data to help reuse of materials of a new building	Increase process transparency
30	This is a practice that relies a lot on the information management of the data of material stock, therefore it has to focus on balancing the information flow and the conversion flow of materials that will be reused in new or refurbished buildings.	Use of material stock data to help reuse of materials of a new building	Balance flow improvement with conversion improvement
31	Giving the ownership of building structures to the manufacturer will make those materials cheaper, since the manufacturer can reuse them later. This helps in the way of reducing the step of buying the materials, because for the client it doesn't matter if the materials will be reused or become waste, so this step removes a non-value step of the construction process.	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building	Reduce the share of non value-adding activities
32	If the ownership of building materials becomes responsibility of the manufacturer, he will know exactly the types of materials and structures in a building that can be reused later, reducing the variability of analyzing and finding the materials that could be reused in the end of life stage of a building.	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building	Reduce variability

33	Knowing exactly who owns each material and structure of a building can help make the process of reusing materials more transparent, since each manufacturer can plan ahead, instead of everything falling down to the hands of the client at the final stage of a building.	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building	Increase process transparency
34	With the development of building material passports, information will be better known and spread among constructors and designers, as it can help them know from the design stage the amount of each material that can be reused or recycled, reducing the variability of only knowing in the end of life stage, making it easier and possible to plan ahead.	Development of material passports	Reduce variability
35	As more information about the reuse potential of materials become available, the flexibility of reusing building materials will grow, as each building can have specific information about the percentage of materials that can be reused or recycled.	Development of material passports	Increase output flexibility
36	The spread of building material passports will allow buildings to have a known number and percentage materials and structures that can be reused, making the process of reusing those materials more transparent for the industry.	Development of material passports	Increase process transparency
37	With available information about building materials, it becomes easier for the designers and constructors to contact the final client and show different options of materials, having a better estimate of reuse potential, embodied carbon and other information.	Development of material passports	Increase output value through systematic consideration of customer requirements
38	Having public information of different types of building materials will allow manufacturers to find materials that have better properties than their owns and use those information to improve the quality and properties of their material.	Development of material passports	Benchmark
39	The demolition phase of a building is a step that does not add value to the final product, as is just a way to dispose the building materials at his end of life. In this way, reusing those materials will eliminate this demolition step and reintroduce these materials into the supply chain of construction, adding more value to buildings.	Reuse of building materials in a new construction	Reduce the share of non value-adding activities
40	The reduction in the cycle time that comes with reusing building materials happens because the time that a material would be extracted from nature and processed into the final material is changed into only the time to extract the material from a existing building and some light processing to recycle it or just reusing as extracted.	Reuse of building materials in a new construction	Reduce the cycle time
41	Reusing a building material or structure eliminates the earlier steps in the construction supply chain, as the extraction from nature and processing of the material is not needed, minimizing the number of steps to reach the point of using the material in the construction of a building.	Reuse of building materials in a new construction	Simplify by minimizing the number of steps, parts and linkages
42	Elimination of waste in the production is one of the biggest goals of the Lean Thinking, since is a activity that does not add value to the final product,	Waste reduction	Reduce the share of non value-adding activities

	therefore waste reduction in the construction has the same principles.		
43	Reducing waste generation in the construction can help eliminate or mitigate tasks that increase the cycle time of the construction, since there will be fewer waste to collect and dispose, decreasing the total time of construction.	Waste reduction	Reduce the cycle time
44	By using techniques to reduce the generated waste in a construction, the constructor can learn the challenges and problems found in each step of each construction, allowing these techniques to be improved after the end of each construction, helping minimize the amount of generated waste.	Waste reduction	Build continuous improvement into the process
45	Although the Construction Industry has its particularities, waste reduction is one of the most used practices in multiple types of industries, therefore it makes it possible for constructors to learn macro strategies from other areas and apply in the Construction Industry.	Waste reduction	Benchmark
46	Producing parts of a building structure off-site allows the possibility of having a better control of the process, better planning and layout of the production site, eliminating tasks that could exist in the construction site, reducing transporting activities in the production and other activities that would not add value to the product.	Off-site construction	Reduce the share of non value-adding activities
47	With better control of the production process, the steps can be optimized to reduce the cycle time of producing a structure, something that is much harder to achieve in a construction site, given the bigger number of variables that can interfere with the production.	Off-site construction	Reduce the cycle time
48	Off-site production has less variables and possible interferences to the production than on the construction site, due to the controlled environment, therefore reducing the variability of the product.	Off-site construction	Reduce variability
49	The off-site production allows a better control of the full process, therefore all the steps must be defined earlier as they become more clear, improving the transparency of the construction.	Off-site construction	Increase process transparency
50	Moving the production of building structures and parts to an off-site location reduces the number of involved variances in the construction, allowing the company to better map and control the whole process.	Off-site construction	Focus control on the complete process
51	With a more standardized process flow in the production, the off-site construction gives the possibility to build continuous improvement easier than it is on the traditional construction site, since the off-site construction site will not change to much from one project to another.	Off-site construction	Build continuous improvement into the process
52	This practice happens in a more controlled environment, in which the information flow between processes becomes as important as it is the conversion between them, therefore it demands a balance between flow improvement and conversion improvement.	Off-site construction	Balance flow improvement with conversion improvement

53	The off-site construction is a practice that is based on the production process of other industries, like the manufacture or automotive, therefore it can easily look to replicate the successful cases of these other industries into the construction.	Off-site construction	Benchmark
54	Using a tool in the operation and end of life phases of a building to verify the state of the materials and structures allows the owners to have a better control of all the parts of a building, making it faster and easier to decide in the end of life stage which materials will be able to reused or have to be disposed, eliminating this step in the final stage of the building, in which would be harder to achieve.	Use of a tool to evaluate the state of materials during the lifespan and end of life of a building	Simplify by minimizing the number of steps, parts and linkages
55	The use of this tool in the operation stage of the building gives better data of the state of the materials and structures in the building, making this information available earlier in the life cycle than it would normally be, allowing it to be used on material stock data of their region.	Use of a tool to evaluate the state of materials during the lifespan and end of life of a building	Increase process transparency
56	The use of water management practices to keep the water in the building for more time decreases the amount of natural water the building will use during its operation phase, reducing the step of receiving more potable water.	Use of water management practices	Reduce the share of non value-adding activities
57	With practices like green roofs and living facades, the management of water in the operation of the building becomes more clear and transparent, since they have to be decided back in the building design phase, that does not add value to the building, as it only increases the operation costs.	Use of water management practices	Increase process transparency
58	The use of these water management practices have to be designed earlier in the project, therefore they allow the control of the water resource from the beginning.	Use of water management practices	Focus control on the complete process
59	The use and control of water resources is something much more developed in other industries like agriculture, making it easier to study successful cases that can be applied to the building practices, considering their differences, such as green roofs.	Use of water management practices	Benchmark
60	Controlling the structures and materials of a building during the operation phase allows the possibility to minimize the need for recuperative maintenance, by using preventive maintenance, which usually is cheaper, faster and easier. By reducing the use of recuperative maintenance, it reduces an activity that does not add value to the building.	Minimize recuperative maintenance with preventive maintenance	Reduce the share of non value-adding activities
61	The use of preventive maintenance will reduce the number of problems that a building will face during its operation and end of life phases, therefore reducing the variability of having to make recuperative maintenances.	Minimize recuperative maintenance with preventive maintenance	Reduce variability
62	This practice is essential for the circularity of buildings in their end of life stage, to find which materials or structures can be reused or recycled, postponing the step of disposing them, an activity that will end their value to the building.	Analyze the potential for reuse or recycling of existing materials and if it is feasible comparing to	Reduce the share of non value-adding activities

		using new materials.	
63	The better management of demolition waste is a practice that can help the transparency of the end of life stage, since it can be defined in the building design phase and their final destinations will be known throughout the whole life cycle.	Management of demolition waste	Increase process transparency
64	Although the Construction Industry is different from most industries, it is possible to analyze cases of better management of products in their end of use from other industries and how they handle their disposals.	Management of demolition waste	Benchmark
65	The use of a circularity tool in the end of life stage of a building gives another dimension to the Circular Economy concept, instead of trying to reuse or recycle the materials that would be disposed, it tries to readapt the whole building so that their materials and structures can be used for a longer time, eliminating the step of disposing them in a time that would not be needed.	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment	Reduce the share of non value-adding activities
66	By using this circularity tool, it increases the lifespan of the building, reducing the variability existing in the demolition phase to find the better destination to the disposal of materials.	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment	Reduce variability
67	With this tool, the flexibility of the building is increased, since a building is usually designed and used for only one type of use during its lifespan, but with this practice it can get an alternative use.	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment	Increase output flexibility
68	The use of this practice in the end of life stage of the building makes it easier to consult with the owner and find the best possible refurbishment use from the circularity standpoint and the requirements of the owner.	Use of a circularity tool to evaluate existing buildings and give the best possible solutions to refurbishment	Increase output value through systematic consideration of customer requirements
69	The use of this practice becomes much easier with the use of Design for Disassembly at the building design phase, but even without that it can help reduce the amount of structures that are totally disposed in end of life stage, reducing this non value activity.	Deconstruction of building structures and materials	Reduce the share of non value-adding activities
70	By deconstructing building structures in the end of life stage of a building, it makes the structure gain another use in its lifespan, increasing the flexibility of use of the materials stored in the building.	Deconstruction of building structures and materials	Increase output flexibility
(71)	The practice of Design for Disassembly of building parts makes it necessary to design and manufacture structures that are easier disassembled, sometimes adding more steps to the production process, as it also adds the step of deconstructing and removing the structures at end of life stage of the building.	Design for Disassembly of building structures	Simplify by minimizing the number of steps, parts and linkages

(72)	The change of ownership of building materials in the building actually decreases the power of decision by the owner of the building over the materials and structures that were used in the construction, since most likely the manufacturers will take decisions over those materials that will benefit them and not the owner of the building, in a case of possible refurbishments.	Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building	Increase output value through systematic consideration of customer requirements
(73)	Different from the traditional construction, the off-site construction happens outside of the actual site and it is later transported to the location and assembled there. This assembly of the structure usually has bigger parts that demand more attention and steps in the transportation and assembly phases.	Off-site construction	Simplify by minimizing the number of steps, parts and linkages
(74)	The practice of deconstructing structures at end of life stage of a building removes the necessity of disposing them, however the act of deconstructing, especially for structures that were not designed with that in mind, can be more complicating that simply destroying it, therefore may add more steps to the phase.	Deconstruction of building structures and materials	Simplify by minimizing the number of steps, parts and linkages

6 CONSIDERAÇÕES FINAIS

O principal objetivo desta pesquisa era de encontrar as relações práticas, positivas ou negativas, existentes entre as práticas da Economia Circular para a ICC e os princípios da Construção Enxuta, e se dividiu em quatro objetivos específicos para facilitar o desenvolvimento da pesquisa. A partir destes quatro objetivos foi determinado a divisão da pesquisa em duas partes principais, cada uma responsável por dois dos objetivos específicos.

A primeira parte desta pesquisa foi a realização de uma revisão sistemática da literatura, com a intenção de atingir os objetivos de encontrar os desenvolvimentos recentes de pesquisa para a Economia Circular dentro da construção civil e desenvolver uma lista de atividades e práticas existentes para a construção civil que utilizam os conceitos da EC.

Esta revisão da literatura levou em consideração 45 artigos publicados nos últimos 10 anos que foram revisados por pares ou publicados em conferências. As palavras chaves utilizadas na pesquisa foram escolhidas através da criação de uma rede bibliométrica para o conceito da EC na construção civil e contemplou as bases de dados ScienceDirect, Scopus e Web of Science.

A primeira parte desta pesquisa atingiu o primeiro objetivo específico definido com a divisão de seis áreas de pesquisas diferentes encontradas dentro do estudo da Economia Circular dentro da construção civil: (1) Desenvolvimento da Economia Circular dentro do ambiente construído; (2) Reutilização de materiais; (3) Estoque de materiais; (4) Economia Circular dentro da fase de projetos; (5) Análises de ciclo de vida; e (6) Passaporte de materiais.

A partir da definição das seis principais áreas de pesquisas dentro do tema abordado pela revisão sistemática da literatura, foi possível encontrar os desenvolvimentos recentes da pesquisa dentro de cada linha de estudo, sendo também desenvolvido um quadro resumo de todos os principais resultados obtidos por cada um dos 45 artigos envolvidos nesta revisão.

Além disso, foi possível a criação de uma lista de atividades e práticas, contempladas nos 45 artigos, da construção civil que incorporam os conceitos da Economia Circular. Esta lista foi dividida em cinco fases do ciclo de vida das edificações, em que a etapa de concepção do projeto obteve mais práticas, com 7 práticas no total, mostrando a importância da consideração dos conceitos da

Economia Circular na fase inicial de um projeto de edificação, para que seja possível atingir o objetivo final de circularidade na construção.

Na sequência, foi realizada a segunda etapa desta pesquisa, que foi responsável por buscar atingir os dois últimos objetivos específicos desta dissertação, correlacionar as práticas da Economia Circular para a construção civil, encontradas no primeiro artigo desenvolvido, com os princípios da Construção Enxuta e propor uma sequência de projeto do ciclo de vida das edificações otimizando as práticas da Economia Circular em conjunto com os princípios da Construção Enxuta.

Para atingir estes objetivos, foi desenvolvida uma pesquisa e o resultado apresentado no segundo artigo deste documento, que utilizou o método de análise de conteúdo de Bardin (1977). Através da técnica de análise de relações, foi possível a criação de uma matriz de relações entre as práticas encontradas da EC dentro da construção civil e os princípios da Construção Enxuta desenvolvidos por Koskela (1992).

Esta matriz de correlações encontrou 74 interações no total, das quais 70 foram positivas e 4 negativas, entre os dois temas relacionados. Todas as interações teóricas encontradas foram descritas na pesquisa, sendo encontrado que o princípio da CE que está mais presente dentro das práticas da EC para a construção civil é o de “redução da parcela de atividades que não agregam valor”, em que teve interações positivas com 15 das 20 práticas listadas. Além disso, a prática de construção fora do canteiro de obras obteve o maior número de interações positivas com os princípios da CE, com 8 interações.

A análise da matriz de relações desenvolvida possibilitou a criação de uma sequência de projeto para o ciclo de vida das edificações, que utiliza as práticas da EC que mais se assemelham aos conceitos da CE. Esta sequência teórica projetaria a edificação com o uso de estruturas modulares, fazendo uso dos dados de estoques de materiais existentes em sua região. Os materiais escolhidos para a construção seriam aqueles que possuem Passaportes do Material de Construção, que possibilitam uma análise mais detalhada dos potenciais de reuso e reciclagem destes materiais desde a fase de concepção do projeto.

Na etapa da construção, este projeto otimizado utilizaria a construção de grande parte de sua estrutura fora do canteiro de obra, algo que é possibilitado por meio do uso de estruturas modulares. Durante a operação da edificação, práticas de gerenciamento de água seriam utilizadas para diminuir o uso de água potável da edificação, como por exemplo telhados verdes e fachadas vivas. Por fim, na fase do final de vida da edificação, seria utilizada uma ferramenta de circularidade que serviria para analisar as possíveis adaptações da edificação para um novo uso e assim estender sua vida útil.

Ao final desta pesquisa, é possível constatar que as práticas da Economia Circular devem ser aplicadas em todas as fases do ciclo de vida de uma edificação para atingir o objetivo de circularidade, principalmente na fase de concepção de projeto, pois nela a maior parte de decisões de materiais e estruturas será tomada, sendo crucial para que a taxa de reaproveitamento dos materiais seja a mais alta possível.

Também foi constatado que grande parte das práticas da Economia Circular para a construção civil tem a presença de um ou mais princípios da Construção Enxuta em sua concepção. Isto ocorre, pois, a EC busca a eliminação do conceito de desperdícios dentro de sua cadeia de produção, buscando que todos os materiais sejam de alguma maneira reaproveitados, preferencialmente que mantenham máximo valor pelo maior período de tempo possível, enquanto a CE busca a maior eficiência na produção através da eliminação de todas as atividades que não agregam valor ao produto final, ou seja, desperdícios que possam ocorrer durante as fases da produção. Apesar do objetivo da redução destes desperdícios na CE seja redução de custos, a redução de desperdícios e reaproveitamento de materiais na EC também trará redução de custos ao longo prazo. Esta similaridade entre os conceitos, faz com que ao se utilizar uma prática da EC no ambiente construído, o uso do conceito de CE esteja mais próximo de ser atingido na edificação.

Apesar dos resultados obtidos na pesquisa serem positivos para a interação entre as práticas da Economia Circular dentro da construção civil e o a Construção Enxuta, esta combinação de conceitos é algo ainda muito novo dentro da ICC, sendo necessário uma maior exploração de pesquisa dentro deste campo. A partir disto são propostos os seguintes trabalhos futuros para continuação de pesquisa dentro da linha de estudo desenvolvida nesta dissertação:

- Estudo de casos reais que utilizem práticas de Economia Circular dentro da ICC para verificar o grau de adoção do conceito de Construção Enxuta, para comparar com os resultados teóricos obtidos nesta pesquisa.
- Análise das interações entre as práticas da Construção Enxuta e os princípios da Economia Circular.

- Desenvolvimento e aplicação de práticas que incorporem os conceitos da Economia Circular e Construção Enxuta em conjunto.

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ANEXO 1 – LOCAL DE PUBLICAÇÃO DO ARTIGO “CIRCULAR ECONOMY IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC LITERATURE REVIEW”

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