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Exploring the 'R's and constructing the big picture of 'recycling' in architecture and construction industry

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Abstract

In the current scenario, the three 'R's 'reduce, reuse and recycle' have been extended to fourteen 'R's due to the increasing awareness to the impacts generated by the extraction of natural resources, manufacturing of goods as well the disposal of the post consumer goods. Even though the meanings associated with 'R's have been increasing, studies have revealed a gap in distinguishing the various degrees of recycling. It is in this context, thematic analysis has been adopted to construct an overall picture of recycling with a thrust on architecture and construction industry. This paper has attempted to explore the 'R's, the definitions and classification of recycling by authors in diverse domains and have been consolidated and synthesized. Findings reveal that 'upcycling' and 'upgrading' are the subsets of recycling. Six degrees of upcycling have been recognized in architecture and the construction sector that revolve around existing building stocks, salvaged building components and building materials with recycled content. In addition, this paper reinstates the need for a 'pre-process' phase specific to developing engineered building materials with recycled content especially with secondary resources from domains other than the construction domain.

Keywords
Architecture, Construction industry, Recycle, Thematic analysis, Upcycle.

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1. Introduction

Archaeological studies have traced the origins of ‘reuse and recycle’ to the Palaeolithic era. ‘Reuse and recycle’ that were once deeply intertwined with the values of the people belonging to the lower Palaeolithic era witnessed numerous paradigm shifts as centuries of years rolled. At one point of time, the essences of ‘reuse and recycle’ began to fade among the people. The diversification and indifference towards recycling was predominantly due to people’s attitude towards the conservation of resources, observed to be highly specific to place and time.

Initially, natural resources were predominantly used for meeting the day to day needs and activities. However with the advent of industrial revolution in the 18th century, goods with numerous manufactured materials became part played of the day to day life activities of the people. Along with the plethora of new materials came the problems and threats that had impacts on diverse realms of our planet that include the lithosphere, atmosphere, hydrosphere, biosphere and the technosphere. Mankind began to grapple with the threats posed in the environment due to improper management and disposal of the used goods. With an intention to find solutions, age old practices of reuse and recycle that were once deeply rooted in the cultural values of the people were revived in the modern context. The 1970s witnessed the revival of the three ‘R’s, ‘reduce, reuse and recycle’. From then onwards, ‘R’s have been gaining momentum.

The term ‘recycle’ has been often associated with ‘upcycling,’ ‘recirculation,’ ‘upgrading,’ ‘downcycling,’ ‘downgrading,’ ‘cascading’ etc. Further, ‘recycling’ has been classified as ‘open loop recycling,’ ‘closed loop recycling’ and also as ‘cradle to cradle’ approach. Van Ewjik and Stageman (2016) have posited that there has been a gap in distinguishing the degrees of ‘recycling’.

The goal of this paper is to construct the big picture of ‘recycling’ focusing on architecture and construction sector. With an intention to meet the formulated goal, objectives such as tracing the origins of recycle in history, understanding the diverse R’s, exploring the approaches to recycling in architecture, coding the degrees of upcycling are framed. Hence, there is an utmost need to explore, synthesize and construct the big picture of ‘recycling’ in a wider spectrum from diverse perspectives with a thrust on architecture and the construction domain. For meeting the aforementioned objectives, ‘thematic analysis’ is adopted as the methodology in this paper.

2. Methodology

Thematic analysis is reported as a method for ‘identifying, analysing and reporting patterns within data’ (Braun & Clarke, 2006). It is recognized as a flexible method that facilitates to analyze and interpret the data from diverse perspectives (Braun & Clarke, 2012). It is effective to analyze interpretative studies that seek to discover something new that involves data collection, deductive and inductive approaches, and analyse two different phased data, followed by coding and categorizing (Alhojailan, 2012). The selection, collection and analysis of data need to be transparent in thematic analysis (Joffe, 2012). Hence, this section elaborates on the data collection and analysis phase.

2.1. Data collection

This study revolved around the tracing of ‘reuse’ and ‘recycle’ in history, followed by the various ‘R’s to construct the big picture. Articles were sourced from the secondary resources with search engines like ‘Google Scholar’, ‘Academia’, ‘Scribd’ and ‘Research Gate’ from 14th March 2019 to 31st May 2019. The search for the handbooks, research articles including undergraduate, postgraduate and doctoral research reports were done at three levels.

Firstly, phrases like ‘material recirculation’, ‘do it yourself’, ‘waste prevention’, ‘waste minimization’, ‘urban mining’, ‘found resources’, ‘wealth from waste’, ‘waste management’, ‘cradle to cradle approach’, ‘material and product centric recycling’, ‘recycling and eco-products and eco-effectiveness’ were used to understand the essence of ‘recycling’ broadly. Secondly, terms such as ‘reduce’, ‘reuse’ and ‘recycle’, ‘upcycle’, ‘re-contextualization’, ‘downcycle’ and ‘cascade’ were used to identify the appropriate research articles. Thirdly, the search was narrowed down to explore 'recycling in architecture' and hence phrases such as 'adaptive reuse', 'junk as a building material', 'building materials with recycled content', 'material re-contextualization in architecture' were used. Besides, postulates, theories, logics and approaches posited in architecture and construction domain were also searched for. The contents were consolidated, synthesized to construct the 'big picture' of 'recycling', which in turn facilitated the positioning of 'upcycling' within the boundaries of 'recycling', interpreting the meaning and the degrees of 'upcyling' in architecture and construction domain.

Around one hundred and twenty six papers addressing 'recycling' and 'upcycling' broadly from the historical period to the current scenario and specific to architecture and construction sector were identified. The titles were grouped under various heads such as 'waste management', 'wealth from waste,' 'creativity and wastes,' 'sustainability and innovation,' 'circular economy,' 'urban mining,' 'R's and 'upcycling,' 'recycling and architecture.'

2.2. Data analysis

The number of research articles published under various heads as discussed in the section 2.1 display the ways through which 'recycling' has been explored in diverse directions. The various definitions of 'recycling', classification and the process facilitated the construction of knowledge inductively. The meanings and practices were consolidated, synthesized and interpreted adopting the principles of the thematic analysis inductively.

The theories, postulates and approaches addressing 'recycling' in architecture and construction sector served as the base for the deductive analysis. The findings of both the inductive and deductive analysis are synthesized to understand the concept of 'recycling' holistically, interpret the meaning as well as the degrees of 'upcycling', specifically to construct the big picture of recycling in architecture and construction domain.

3. Findings

Around 11.9% of articles were observed to fall under 'waste management' category. The number of papers classified as 'wealth from waste' accounted 5.7%. Nearly 22.2 % of articles were grouped under 'creativity and wastes.' 'Sustainability and innovation,' 'postulates and theories in architecture,' 'urban mining' accounted 4.7% each. The articles classified as 'circular economy,' 'R's and 'upcycling' accounted 8.7% and 7.9% respectively. Nearly 29.5% of articles were identified under the 'recycling and architecture.'

3.1. Tracing the roots of 'reuse' and 'recycle' in history

In ancient civilizations, people identified several methods towards the managing of wastes. People followed the principles of 'reuse', 'repurpose', and 'recycle' as strategies for two reasons. Firstly, it reduced the time and efforts spent in the extraction of natural resources. Secondly, it prevented the entry of goods beyond repair into the landfills.

In history, 'recycling' was referred as 'scavenging' (Downs & Medina, 2000). People observed 'recycling' as a fundamental value (Rathje & Murphy, 2001). However, the reasons for recycling varied with respect to people, place and time. Studies on archaeological excavations in different sites around the world display that people adopted the principles of 'reuse' and 'recycle' right from the 10th century onwards. Right from the prehistoric era, humans have been sensitive to the extraction of natural resources (Cohen & Yosef, 2015). It has been posited that under certain circumstances, homohabilis addressed wastes as resources (Havlicek, 2015). For instance, lithic reclamation emerged in the Lower Paleolithic era (Lemorini at al., 2015) and Middle Paleolithic era (Amick, 2015).

With respect to time, the reasons for reuse and recycle varied amongst the people. Romans practiced 'recycling,' with the perspective of effectively managing both the financial resources as well as the virgin materials (Gilchrist, 2015). The economic growth in the Roman period developed a sense of disinterest towards 'recycling' amongst the people (Claridge et al., 2010). However, it has been posited that Romans adopted 'reuse and recycle' with a focus to conserve financial resources.

In archaeology, 'reuse addressed a change in the use, user or form of an artefact after serving a specific function in a particular activity' (Schiffer, 2016). Four kinds of reuses, such as 'conservatory process,' 'lateral cycling,' 'secondary use,' and 'recycling,' were identified. In the conservatory process, lateral cycling and secondary use by retaining the true forms were adopted. During that time, recycling was considered as a kind of 'reuse', where the structure of the object was modified.

From the 1930s and the 1940s, 'recycling' was practiced in the army camps during the world war when resources were scarcely available (Benjamin, 2011). Comprehending the issues generated by diverse man-made materials, the spirit of 'recycling' was revived during the 1970s. With an intention to understand 'recycling' from a wider perspective, the following section discusses the various terms associated with 'R's.

3.2. An overview of 'R's after the 1970s

People realized the threats posed by the generation, types, improper handling and management of wastes. This complexity witnessed the emergence of reusing and recycling of the discarded goods for the same or different purposes. During the early 1970s, the origin of three R's, 'reduce, reuse and recycle' was advocated by Ontario's Pollution Probe (Hoornweg & Tata, 2012). As years rolled by, the meanings associated with 'R's have been interpreted in diverse directions. As a result, the three fundamental 'R's, namely, 'reduce, reuse and recycle' began to increase gradually with a deeper thinking focusing on diverse strategies to address the wastes as resources that prevent or reduce their entry into the landfills.

Table 1. *From three to fourteen 'R's.*

From the 1970s onwards	Three to ten 'R's		
Ontario's Pollution Probe in the 1970s (O'Connor, 2015)	Reduce, Reuse, Recycle		
Environment Protection Act 1970– Waste framework directive	Avoidance, Reuse, Recycling, Recovery, Treatment, Containment, Disposal		
Resource Conservation and Recovery Act (1976)	Reduce, Reuse, Recycle		
European commission Directive 2008/98 – Waste management hierarchy	Prevention, Preparation for reuse, Recycling, Recovery, Disposal		
Sustainable development institute (2008)	Reduce, Reuse, Recycle and Recovery		
Davidson (2011)	Prevention, Reuse, Recycling, Rethink or Recovery or Re-buy , Disposal		
Waste management hierarchy (Hoornweg and Tata, 2012)	Waste diversion – Reduce, Reuse, Recycle, Recover; and Waste disposal- Landfill, Incineration and Controlled dump		
Dickey (2008)	4 'R's	Reduce, Reuse, Recycle, Recover	
CRRA (2009)	5 'R's	Reduce, Reuse, Recycle, Recover, Rethink	
Greenlane diary (nd)	6 'R's	Reduce, Reuse, Recycle, Respect, Replenish and Refuse	
Alatervo (2013)	6 'R's	Rethink/ Reinvent, Refuse, Reduce, Reuse/Repair, Recycle, Replace/Re-buy	
Swafford (2015)	7 'R's	Reuse, Repurpose, rot, repair, return, refill and refuse	
Abella (2013)	8 'R's	Reduce, Replace, Reuse, Recycle, Recover, Refuse and Reject, Rethink	
Earth Month org (2014)	10 'R's	Respect, Refuse, Reduce, Reuse, Renew , Recycle , Responsibility , Rethink, Replant, Restore	
Ten 'R's (Reike et al., 2018)	Resource retention loops	Shortest loop	Refuse (R_0), Reduce (R_1), Resell/ Reuse (R_2), Repair (R_3)
		Medium loop	Refurbish (R_4), Remanufacture (R_5), Repurpose (R_6)
		Long loop	Recycle (R_7),Recover (R_8) and Re-mine (R_9)
		Reservitisation (R_{10}) highly interrelated with reuse and so not listed as a separate R	
Lisa (2014)	14 'R's	Reduce, Reuse, Recycle, Respect, Refuse, Replenish, Rethink, Repair, Reinvent, Recover, Responsibility, Replant, Restore, Rot	

Currently, ways to handle wastes fall under the diversion and the disposal categories (Hoornweg & Tata, 2012). The four R's, 'reduce', 'reuse', 'recycle', and 'recover' have been included under the category 'diversion'. The 'disposal' category has comprised the landfills, incineration, and the controlled dump. Besides, the fourth 'R' represented 'rethink' or 'recover' or 're-buy' (Davidson, 2011). The three 'R's during the 1970s have been extended to many 'R's in the present context. The other 'R's have been associated with 'replenish,' 'rethink,' 'respect,' 'responsibility,' 'replant,' 'rot' and 'restore'. 'Reduce, reuse and recycle' has marked the origin of the 'R's which has been extended to 14 'R's in today's context are summarized in Table 1.

Ten 'R's to retain the resources in the supply chain that fall under the short, the medium, and the long loop have been recognized (Reike et al., 2018). Refuse (R_0), Reduce (R_1), Resell or Reuse (R_2), Repair (R_3) have been included in the short loop. Medium loop addressed Refurbish (R_4), Remanufacture (R_5), and Repurpose (R_6). Recycle (R_7), Recover (R_8) and Re-mine (R_9) have been categorized as the long loop resource retention option. Reservitisation (R_{10}) has been observed to be intertwined with Recycle (R_6). Hence, R_{10} has not been listed as a separate 'R.'

When materials from the discarded products serve as the resources for developing a new product, it has been addressed as 'design from recycling' (Ragaert, 2016). Materials extracted from the discarded or post consumer goods or materials sourced through demolition of building stocks have been recognized as 'freely available' or 'secondary resources.'

Four 'R's (Dickey, 2008); five 'R's (CRRA, 2009); six 'R's (Greenlane diary, nd; Alatervo, 2013), seven 'R's (Swafford, 2015); eight 'R's (Abella, 2013), ten 'R's (Earth Month org, 2014) and fourteen 'R's (Lisa, 2014) have been identified from various blogs. According to Lisa (2014), fourteen 'R's revolving around 'reduce', 'reuse', 'recycle', 'respect', 'refuse', 'replenish', 'rethink', 'repair', 'reinvent', 'recover', 'responsibility', 'replant', 'restore' and 'rot' (Lisa, 2014) have been identified.

3.2.1. 'R's and the waste management

Understanding the problems generated by the disposal of commodities and other related goods, the waste management hierarchy was framed during the1970s (Lazarevic et al., 2010). 'Avoidance', 'reuse', 'recycle', 'recover', 'treatment', 'containment' and 'disposal' have been the various ways to manage wastes generated (Environment Protection Act, 1970). According to the Directive 2008/98/EC, 'prevention', 'reuse', 'recycle', 'energy recovery' and 'disposal' have been prioritized hierarchically to deal with wastes. 'Prevention' thus focused on the measures to be taken so as not to generate any wastes, which always has been considered as an ideal situation. 'Reuse' addressed the repurposing of discarded objects by valuing the material used, the intention of the form as well as the structure itself.

Gertsakis and Lewis (2003) outlined a simple description of environmental attributes that include 'reduce', 'reuse', 'recycle', 'treatment' and 'disposal'. 'Reduce' has been the most desirable outcome whereas disposal has been the least desirable option. The goal to 'recycle' has been considered to be predominantly 'ameliorative' and 'partly preventive'. The recycled outcomes fall in between the most and the least desirable categories. However, waste management hierarchy has been criticized as 'disposal' based waste management by the environmentalists.

3.2.2. 'Recycling' after the 1990s

According to Merriam Webster dictionary, the term 'recycle' is listed as a 'hypernym.' It is observed to be both a noun and a verb. 'To pass through a series of changes or treatments' is the expression of the noun, whereas 'to adapt to new use,' and the 'process' refer to a verb. The hyponyms of 'recycle' are 'downcycle' and 'upcycle,' expressing narrower or more specific meanings.

Reprocessing of extracted materials from products at the end of life to return them into the supply chain to create new products has been 'recycling' (Worrel & Reuter, 2014). 'Recycling' has addressed the integration of collection schemes supported with the value-based conception of waste (Van Ewijk & Stagemann, 2016). Oyenuga and Bhamidimarri (2017) have recognized 'recycling' as a comprehensive way to manage the wastes effectively. Recovery and disposal have been the last two strategies in the hierarchy. 'Recovery' has been associated with the retrieval of energy from waste. The entry of wastes into the landfills has been associated with dumping.

3.2.2.1. Classification of 'recycling'

'Recycling' has been a strategy to retain the materials extracted from the discarded goods as resources. Connelly and Koshland (1997) have identified 'recirculation,' 'upgrading,' and 'cascading' as the three levels of recycling. 'Recirculation' has addressed the use of secondary resources without any change in the inner material. When the original structure has been partly retained, it has been referred as 'partial recycling.' The reuse of material or the product in the degraded form of material quality while compared with the pre-consumed state has been recognized as 'cascading'.

Direct reuse, non-destructive, and conventional recycling based on the level of structural and material deformation have been associated with 'recycling' (Allwood et al., 2011). A product in the original form or with a superficial change in the surface for a different purpose has been classified as of 'direct reuse.' Non-destructive recycling has been sub-classified as 'deformative,' 'subtractive,' and 'additive'. Physical modification of the product has been observed to fall under the 'deformative' category. Materials extracted from the original products have been recognized as a 'subtractive' approach. When products have been joined or connected, it has been recognized as an additive version of non-destructive recycling. When the material has been completely broken down as a feedstock, it has been known as conventional recycling.

Recycling has addressed the reprocessing of the secondary materials into the same product or materials or substances for the same or a different purpose (Goorhius & Bartl, 2011). Product recycling, material recycling, feedstock recycling, and downcycling have been recognized as the categories of recycling. Product recycling has addressed the repurposing of the product in its true form for various other applications. The modification of the physical form without changing the chemical composition has been termed as product recycling. Reprocessing of the physical and chemical constitution into the original constituents has been feedstock recycling. Downcycling has been denoted as any recycling process that resulted in a product with lower quality.

'Recycling' has been interpreted as 'functional,' 'upcycling' and 'downcycling' (Niinimaki, 2013; MacArthur, 2013). The process of recovering materials for the original or different purposes, excluding energy recovery, has been termed as 'functional recycling'. The method of converting materials for lesser quality and reduced functionality has been 'downcycling.' When the focus has been on higher quality and increased 'functionality,' it has been recognized as 'upcycling.'

The reintroduction of discarded materials back into industrial production, returning them into the supply chain has been addressed as 'recycling' (Hung et. al, 2012). Szaky (2014) posited the significant role played by the confluence of material composition, kind, and intention of the discarded goods in determining the purpose during the second life.

Repurposing of secondary resources from the material perspective has been also addressed as recycling. Closed-loop production has addressed reuse, recovery, and remanufacture, where the products have been collected from the manufacturing of the original product (Rashid at al., 2014).

Worrel and Reuter (2014) posited 'recycling' to be 'product and material centric.' Material centric has been a subset of the product-centric approach. It has been a channel to achieve resource efficiency. Broadly, primary, secondary, tertiary and quaternary have been identified as the four types of recycling. The re-extrusion of pre-consumer scrap has been recognized as primary recycling. The mechanical treatment of the secondary resources has been known as secondary or physical recycling, modification of the chemical properties has been tertiary and quaternary treatment has focused on energy recovery (Ignatyev et al., 2014).

According to Elkersh and Haggar (2015) upcycling, recycling, and downcycling have been the three types of recycling that correspond to the development of products with a higher, equal, or lower value. However, upcycling and recycling addressed the manufacturing of goods with higher or equal value when compared to the original application.

3.2.2.2. Interpreting the classifications of 'recycling'

Authors have classified 'recycling' in many ways. As discussed in the previous section, the nomenclature developed by authors like Conelly and Koshland (1997); Allwood et al. (2011); Goorhius and Bartl (2011); Niinimaki (2013); MacArthur (2013); Ignatyev et al. (2014), Elkersh and Hagger (2014) are summarized in Table 2.

It is observed that the various definitions are grouped, regrouped and interpreted to fall under 'material

Table 2. *Interpreting the classifications of 'recycling'.*

Authors	Classification	Description	Interpretation
Connelly and Koshland (1997)	Upgrading	Addition of energy to bring back the original structure to a pre-consumed state	Material centric
	Cascading	Use of material or product in degraded form	Product centric
	Recirculation	Repurpose in true form	Re-contextualization
Allwood et al., (2011)	Non destructive recycling: Deformative	Physical modification	
	Non destructive recycling: Additive	Goods are joined or connected	
	Non destructive recycling: Subtractive	Extraction of materials from original goods	Material centric
	Conventional	Materials completely broken down as feed stocks	
Goorhius & Bartl (2011)	Product recycling	Physical and chemical constitution is retained	Re-contextualization
	Material recycling	Only chemical constitution is retained	Material centric
	Feedstock recycling	Chemical constitution of material: Reprocessed in to original constituents	
	Downcycling	Chemical constitution of material: Degraded	
Niinimaki (2013); MacArthur (2013)	Functional	Process of recovering materials for the original or different purposes	Product centric
	Upcycling	Converting materials for better quality and functionality	
	Downcycling	Converting materials for lesser quality and reduced functionality	
Ignatyev et al. (2014)	Primary	Re-extrusion of pre-consumer scrap	Material centric
	Secondary	Mechanical treatment of the secondary resources	
	Tertiary	Modification of the chemical properties	
	Quaternary	Recovery of energy	
Elkersh & Hagger (2015)	Downcycling	Products: Lower value	Product centric
	Upcycling	Products: Higher value	
	Recycling	Products: Original value	

Table 3. *From 're-contextualization' to 'upgrading'.*

Authors	Classification	Description	Interpretation
Connelly and Koshland (1997)	Upgrading	Addition of energy to bring back the original structure to a pre-consumed state	Material centric
	Cascading	Use of material or product in degraded form	Product centric
	Recirculation	Repurpose in true form	Re-contextualization
Allwood et al., (2011)	Non destructive recycling: Deformative	Physical modification	
	Non destructive recycling: Additive	Goods are joined or connected	
	Non destructive recycling: Subtractive	Extraction of materials from original goods	Material centric
	Conventional	Materials completely broken down as feed stocks	
Goorhius & Bartl (2011)	Product recycling	Physical and chemical constitution is retained	Re-contextualization
	Material recycling	Only chemical constitution is retained	Material centric
	Feedstock recycling	Chemical constitution of material: Reprocessed in to original constituents	
	Downcycling	Chemical constitution of material: Degraded	
Niinimaki (2013); MacArthur (2013)	Functional	Process of recovering materials for the original or different purposes	Product centric
	Upcycling	Converting materials for better quality and functionality	
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	Secondary	Mechanical treatment of the secondary resources	
	Tertiary	Modification of the chemical properties	
	Quaternary	Recovery of energy	
Elkersh & Hagger (2015)	Downcycling	Products: Lower value	Product centric
	Upcycling	Products: Higher value	
	Recycling	Products: Original value	

centric,' 'product centric' as well as 're-contextualization.' However, the definitions of 'upcyling' and 'upgrading' are observed to be varying. With an intention to understand the definitions and meanings, this paper has attempted to explore 'upcycling' and 'upgrading' in detail.

3.3. Interpreting the definition of 'upcycling' and 'upgrading'

Nearly twenty one definitions were identified that are classified as 're-contextualization' and 'upgrading for high end applications.' Around one-third are identified to be falling under 're-contextualization.' Two-thirds are observed to be revolving around the 'product and material centric.' The latter was around 41.66% to be 'material centric' and 58.44% to be both 'material and product centric' as in Table 3. From the definitions, it has been observed that the essence of upcycling has been adopting the principles starting from 're-contextualization' to 'upgrading' and 'upcycling,' representing the lowest and the highest levels respectively.

3.4. From 're-contextualization' to 'upgrading'

The Merriam-Webster dictionary decodes the term 're-contextualize' as a transitive verb that means to place something in a different context. 'Re-contextualization' has been addressed as the repurposing of discarded items in different contexts (Pennycook, 2007). Re-contextualization has included the transformation of discarded goods for different purposes with or without modifying the original form facilitated with or without energy.

A German engineer, Reiner Pilz coined the term 'upcycle' (Kay, 1994). It addressed the process of converting waste materials into new materials or products of better quality as well as environmental values (Nyaguthii, 2013; Mansouri & Seyedeh, 2014). Upcycling has generated positive impacts on the environment (Ebbert et al., 2017). It has been established that designers need to be creative, critical, and think out of the box to develop innovative and inventive upcyled outcomes (Ali et al., 2013). Upcycling focused on maintaining or upgrading resource quality and productivity through many cycles of use (Braungart, 2007). Glaveanu (2016) reported 'upgrading' as a direction to add value to the secondary resources while developing high end applications. The definitions of 'upcyling' including 'upgrading' have been consolidated in Table 3.

From the classification of definitions, it is observed that Conelly and Koshland (1997) have used the term 'upgrading', whereas Niinimaki (2013), MacArthur (2013) and Elkersh & Hagger (2015) have used the term 'upcycling'. According to Conelly and Koshland (1997), 'upgrading' has been a process where the original structure of the material has been retained. Glaveanu (2016) has used both the terms 'upgrading' and 'upcycling' with the thrust on perfect mix while developing high end products. From the various definitions, the authors have observed that 'upcycling' has been predominantly associated with developing high end applications.

In this context, the authors have interpreted 'upgrading' as process of developing materials extracted from secondary resources by enhancing the properties so as to manufacture high end applications. Hence, 'upgrading' is identified as a subset of 'upcycling.'

3.4.1. Relationship between 'recycling', 'upcycling' and 'upgrading'

The relationship between 'upcycling,' 'downcycling,' 'upgrading,' 'product and material centric,' 'closed loop and open ended recycling' has been integrated and mapped in Figure 1. Irrespective of open or closed loop recycling, materials and products play important roles. When the properties of the secondary resources have been degraded for developing low end applications, it has been observed as 'cascading' and hence excluded in identifying the degrees of upcycling.

According to Petruch (2015), 'recycle' is observed at the material, component and product level. 'Recycle' is classified as 'downcycle', 'upcycle' and 'functional'. As shown in Figure 1, 'downcycle' and 'upcycle' are found to be predominantly material centric. When the focus is to recycle the 'function' for the same or different purpose, it is identified as closed and open ended. When the focus is on developing 'high end applications,' 'upgrading' of

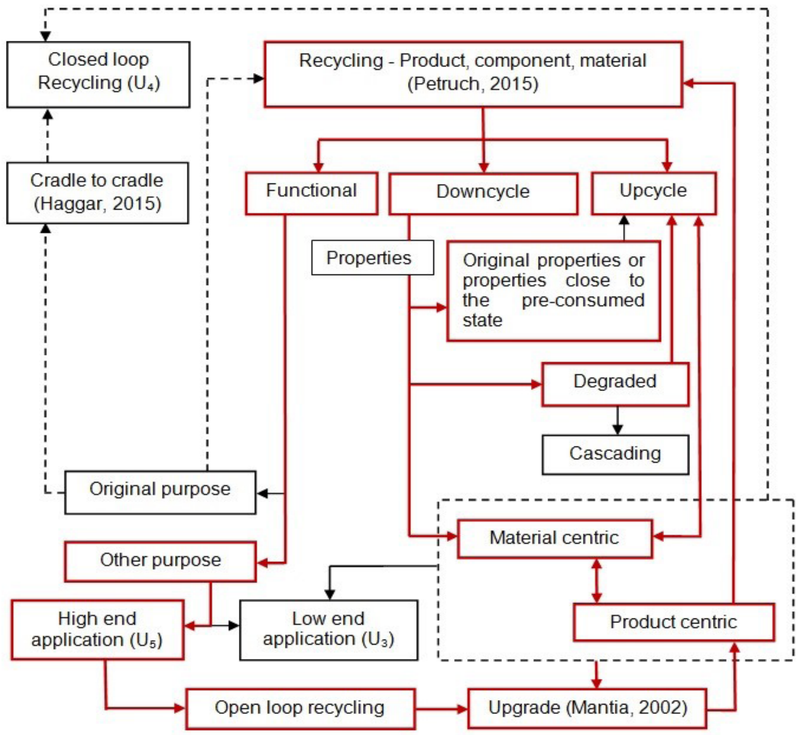

Figure 1. *An insight into 'recycling'.*

secondary resources is identified as a pre-requisite. This is 'product centric', whereas investigating the properties of the secondary resources serves as the subset, where 'upcycling' comes in to the picture. But, when only the properties of secondary materials is the focus, it is predominantly material centric.

3.4.2. Degrees of 'upcycling'

The six degrees of upcycling include re-contextualization of the discarded goods in their true forms (U_0); re-contextualization of the discarded goods through physical modification, without energy (U_1) and with energy (U_2); downcycling for low end applications in other domains without degrading the materials or with properties that do not fully correspond to the pre-consumed state (U_3), recycling materials for the original application (U_4) and upgrading secondary resources for developing high end applications (U_5) as in Table 4.

The first three degrees of upcycling include U_0, U_1 and U_2 that fall under Repurpose (R_6). Recycle (R_7) includes U_3, U_4 and U_5. U_3 and U_4 constitute the long and the longer resource retention loops. U_3 is also known as partial recycling, where secondary materials

Table 4. *Degrees of 'upcycling'.*

<table>
<tr><th>Resource retention</th><th colspan="2">Degree</th><th colspan="5">Upcycling</th></tr>
<tr><td rowspan="3">Repurpose (R_6)</td><td colspan="2">U_0</td><td colspan="2" rowspan="3">Re-contextualization (medium loop)</td><td>Discarded goods in their true form</td><td rowspan="6">Functional recycling</td><td rowspan="3">With or without modifying the true forms</td></tr>
<tr><td colspan="2">U_1</td><td>Physical modification of discarded goods without energy</td></tr>
<tr><td colspan="2">U_2</td><td>Physical modification of discarded goods with energy</td></tr>
<tr><td rowspan="3">Recycle (R_7) (Materials are extracted from the secondary resources)</td><td>Long</td><td>U_3</td><td rowspan="3">Retain the original properties of the materials or properties that do not fully correspond to the pre-consumed state</td><td rowspan="3">Material and product centric</td><td>Low end applications</td><td>Open loop</td></tr>
<tr><td>Longer</td><td>U_4</td><td>Recycling - original application</td><td>Closed loop</td></tr>
<tr><td>Longest</td><td>U_5</td><td>Upcycling and upgrading of secondary resources in the same or a different domain (longest resource retention loop)</td><td>Open loop</td></tr>
</table>

with original are properties close to the pre-consumed state are considered. Upgrading of secondary materials for high end applications is the highest degree of upcycling (La Mantia, 2002) as shown in Figure 1. Upgrading constitutes the longest resource retention loop. While developing high end applications, investigating the potentials of the secondary materials have been playing a crucial role. However, due to the lack of adequate knowledge on secondary resources, upcycling and upgrading has been less popular amongst the design community (Xu & Gu, 2015).

3.5. Recycling in architecture

During the Roman era, building materials from the existing building stocks were recycled. 'Recycling' surfaced as a strategy primarily to manage the fiscal as well as the mineral resources effectively (Gilchrist, 2015). Existing building stocks, salvaged components and building materials with recycled content have been the three directions to 'recycling' in architecture. The following sections discuss the different strategies adopted for adaptive reuse of the existing building stocks, utilization of salvaged components and developing building material with recycled content.

3.5.1. Adaptive reuse

The reuse of heritage buildings has been a direction to sustainability (Bullen & Love, 2011). The reuse of buildings or sites for an application utterly different from the original function has been addressed as 'adaptive reuse' (Moshaver, 2011). 'Typological,' 'technical,' and 'strategic' have been the three approaches adopted in the adaptive reuse. The typological approach addressed the usage of a building for a different use when compared to the original function. The integration of services or improving the conditions has been identified as the technical approach. The strategic approach has been the process and strategies used for adapting the built structures. However, Plevoets and Cleempoel (2013) acknowledged a poetic understanding of the adaptive reuse has been recognized as another direction to the strategic approach.

According to Pleevoets and Cleempoel (2014), adaptive reuse has been challenging. Renaissance concepts addressing 'following,' 'translation,' 'imitation' and 'empathy' evolved concerning the adaptive reuse of the interior spaces. Under the class 'following,' critical attitude was excluded. 'Translation' included both critical and creative stances. 'Imitation' was applied in projects liberally to evolve a relation between the original and the created version. Capturing the original elegance of the interiors has been very empathetic. Whatever the approach be, cost has played a crucial role in adaptive reuse of existing buildings stocks by restoring the interiors for different occupancy, (Bullen & Love, 2011).

3.5.2. Salvaged building components

According to Chan (2007), 'salvaging' has been addressed as the reuse of whole elements retrieved during the demolition of old buildings. According to Daketi (2013), three ways to address recycled building materials have been identified. 'Conventional reuse' has focused on the application of salvaged materials from older structures. 'Repurposing' of salvaged material for different applications has been addressed as 'adaptive reuse.' Recycled content reuse has included the conversion processes of recovered materials into new building material. Ponnada and Kameshwari (2015) have used the term 'architectural salvage' where timber-based components have been disassembled and refurbished.

3.5.3. Building materials with recycled content

Reprocessing of reclaimed materials as new materials or use has been 'recycling' (Dolan et al., 1999). 'Recycling' has implied newness, a result of processing or extracting material and reconfiguring them. The emergent outcomes have been predominantly elemental and experimental expressions (Chan, 2007); expressive and experimental (Carpenter, 2009).

Manufacturing of building materials with recycled content has been termed as 'opportunistic architecture' (Simitch & Warke, 2014). Recycling of materials from the demolition of buildings has been observed to cap the mining of virgin materials (Oyenuga & Bhamidimarri, 2017). The term 'super use' has referred to the applications of secondary resources in the construction sector based on the potentials of discarded materials (Altamura & Baiani, 2019).

'Re-material oriented design' has been addressed as reusing or repurposing or upcycling of secondary resources in an architectural or interior setting (De Castro Pereira, 2017). Re-material oriented design represented as ROD has been an unpredicted non-linear activity that includes intuitive, reflective, skilful, and conscious approaches. Practice has played a significant role in intuitive ROD. The experience of the individuals in the respective fields has been identified as reflective ROD. Directions unravelled adopted through routine practice has been addressed as skilful ROD. Conscious ROD has incorporated continuous modelling of variables to develop appropriate outcomes to be successful. Based on the available or known parameters, individuals interested in upcycling have been observed to fall under the categories I, II, III, and IV as in Table 5.

Table 5. *Interpreting the ROD.*

<table>
<tr><th>Parameters</th><th>Category I</th><th>Category II</th><th>Category III</th><th>Category IV</th></tr>
<tr><td>Goal</td><td rowspan="3">Known</td><td rowspan="3">Known</td><td>Known</td><td>Yet to be defined</td></tr>
<tr><td>Materials</td><td rowspan="3">Yet to be defined</td><td>Known</td></tr>
<tr><td>Process</td><td rowspan="2">Yet to be defined</td></tr>
<tr><td>Skills and tools</td><td>Available</td><td>Unavailable</td></tr>
<tr><td>Framed setting</td><td>Favorable</td><td>Challenging</td><td colspan="2">Unfavorable / highly challenging</td></tr>
<tr><td rowspan="3">Interpretation</td><td>Well defined or stated problem</td><td>Moderately defined</td><td colspan="2">Ill defined or wicked problem</td></tr>
<tr><td colspan="4">The 'ill defined or wicked problem' need to be transformed in to a 'well defined or stated problem'</td></tr>
<tr><td colspan="4">The 'yet to be defined, unfavorable/ highly challenging parameters falling under Category III and IV need to be 'well defined'</td></tr>
</table>

The lack of knowledge and confidence in using recycled building materials prevent the utilization of secondary resources in the construction sector (Munn & Soebarto, 2004). When upcycling has been the goal with little or no knowledge of materials, processes, skills, and tools, the framed setting has been observed to be a challenging task. In such situations, there has been a need to bring the 'ill defined' parameters into a 'well defined state.'

In this context, it has been essential to explore the approaches adopted to recycle and repurpose secondary resources sourced from construction and demolition wastes as well as from domains other than the construction industry and architecture. The following section discusses the approaches, logics, and postulates adopted for repurposing secondary resources in the construction sector. Besides this, the various postulates have been consolidated, synthesized and interpreted in the later section 3.5.4.1.

3.5.4. Postulates, logics and secondary resources

Concerning the utilization of discarded materials in architecture and the construction sector, ideologies posited by archaeologists and architects are interrelated and interpreted to construct the 'big picture' in architecture. Roman's reuse principles; the competing logics of sustainable architecture, rethinking architecture based on 'form follows materials,' and the sustainable approaches are the various theories, postulates and ideals recognized in architecture.

The repurposing of post consumer packaging waste in the construction sector was been traced from the Hellenistic age. After investigating the potentials of 'amphorae,' Romans came up with ideas to reuse and repurpose them in architecture and construction sector (Will, 1997). While doing so, the true forms of the pots with pointed bases were either modified or unmodified. Romans classified 'reuse' as 'A,' 'B,' and 'C' (Pena, 2007). The utilization of amphorae for the same purpose is reuse 'A.' Reuse 'B,' and 'C' denoted the applications in other fields without and with modifications in true forms respectively.

Eco-technical, eco-aesthetic, eco-cultural, eco-medical, eco-social, and eco-centric have been identified as the six competing logics of sustainable architecture (Guy & Farmer, 2001). The first five logics have addressed the technical approaches, fluid forms, culture in context, health of the occupants, and the social aspects respectively right from the generation of ideas, identification of approaches, and concepts. Design, form, materials, construction techniques, building materials, the volume of spaces, operation, and maintenance have been identifies as significant aspects reflect the sustainable values. Among the six competing logics, 'eco-centric' has addressed the diverse ways of repurposing secondary resources in the construction domain.

Gang (2010) has postulated three approaches, namely the cooks', the prospectors' and the nomads.' The three approaches have been formulated based on 'form follows materials.' The cook's paradigm has been about incorporating the leftover products in the building industry for diverse construction purposes. Curiosity, persistence to locate the used materials, evaluate the potential of the identified materials with an intention to give new life in architecture have been recognized as the prospective architects' role. Nomad's approach has been the design of lightweight structures with the potential to be dry assembled at the site.

Architect Pandya (2012) has evolved sustainable approaches like 'A,' 'B,' 'C,' 'D' and 'E.' Approaches like 'A,' 'B,' 'D' and 'E' have addressed the participatory design for traditional wisdom, interpreting the traditional wisdom in a contemporary way , sustainability through design and exploration for eco friendly interiors and exteriors respectively. Approach 'C' has addressed the utilization of recycled wastes as secondary resources in the construction industry.

3.5.4.1. The interpretation

The approaches relating to the applications of secondary wastes in architecture has been interpreted to be a synthesized version of Romans' Reuse 'C'; Guy and Farmer's 'eco-centric' ideal; Gang's nomads' and prospectors' approaches and Pandya's approach 'C' (Ramaraj & Nagammal, 2017). Adaptive reuse and the utilisation of salvaged building components has been observed to fall under 'repurposing' that has been categorized as Romans 'Reuse A' and Gang's Prospector's approach. Developing building materials with recycled content has been interpreted as 'downcycling, recycling and upcycling' integrating the Romans reuse 'B' and 'C' Approach 'C', Gang's Prospector's and nomad's approach. Besides, 're-material oriented design' addressed as ROD is also manifested while developing recycled building materials with construction and demolition waste (De Castro Pereira, 2017). The outcomes of such approaches have led to the emergence of elemental and experimental expressions (Chan, 2007) incorporating both 'repurpose' and 'recycle' falling under R6 and R7 respectively as shown in Figure 2.

4. Conclusion and discussion

The primary goal of this article is to explore 'recycle' from a wider perspective so as to construct the big picture. An in depth knowledge about the origins of recycle in history, understanding the diverse R's, recycling in architecture, coding the degrees of upcycling are explored, consolidated, synthesized and interpreted by adopting 'thematic analysis.'

Firstly, with respect to 'tracing the origins of recycle', research articles from archaeology were identified and explored. It has been observed that our great ancestors have been acquainted with the spirit of 'reuse'. Numerous strategies to reuse as well as repurpose the used goods have been adopted effectively and also creatively.

Secondly, the essences of 'R's after the 1970s is explored. 'Reduce, reuse and recycle' are the three predominant three 'R's that originated initially. As decades passed by, the 'R's have been extended from three to fourteen meanings. However, Reike et al. (2018) have identified ten 'R's such as Refuse (R0), Reduce (R_1), Resell or Reuse (R_2), Repair (R_3) Refurbish (R_4), Remanufacture (R_5), Repurpose (R_6), Recycle (R_7), Recover (R_8), Re-mine (R_9). The tenth 'R', Reservitisation (R_{10}) is not explicitly stated as it is identified as a sub strand of Recycle (R_6).

Literature studies reveal that 'recycle' is classified in many ways. Six types of classifications of 'recycle' are explored and interpreted to understanding the meanings of 'upcycle.' From the various definitions and classifications, it is observed that 'upcycle' is a subset of 'recycle. The explanations of 'upcycle' predominantly focus on the development of high end applications. In this context, it is crucial to mention Glaveanu's definition of 'recycling' stated as 'perfect mix of upcycling and upgrading.' With this definition, the authors have interpreted 'upgrading' as the subset of 'upcycling' where the properties of the secondary resources are enhanced.

Thirdly, adaptive reuse of existing buildings including salvaged building components and building materials with recycled content have been recognized as the three directions for recycling in architecture and the construction sector. Adaptive reuse of existing buildings stocks and the utilisation of salvaged building components for the original purpose have adopted the essences of reuse 'A' and 'eco-centric' ideal. The application of salvaged building components for a different purpose in the construction industry without modification has been classified as reuse 'B' and Gang's prospectors' approach.

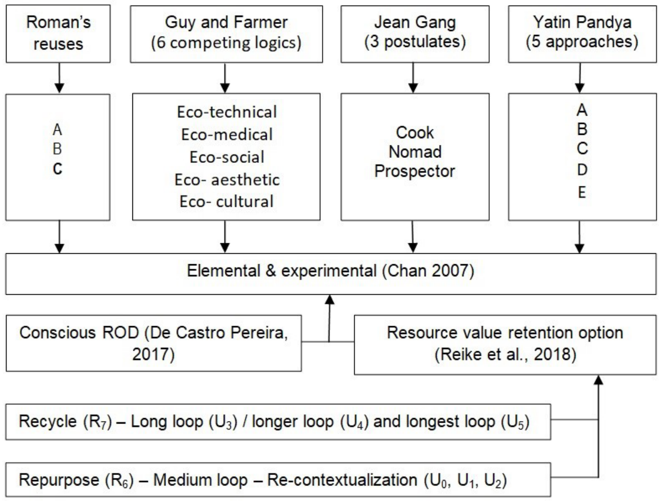

Figure 2. *Amalgamation of theories, logics, approaches and postulates in architecture and the utilization of secondary resources.*

With an intention to meet the fourth objective, the diverse meanings of 'recycle' is integrated with the postulates, logics and approaches observed in architecture. Direct reuse of secondary resources for developing applications in architecture from diverse domains other than the building and construction industry has been observed to be a fusion of 'zero or physical recycling'; 'direct reuse or non-destructive recycling falling under open loop recycling.' Further, direct reuse is recognized as an integrated expression of Gang's cook's and prospector's approaches as well as Roman's reuse 'B' falling under the first three degrees of upcycling U_0, U_1 and U_2. Development of new applications falls under U_5 and includes reuse 'C' and Gang's prospector's approach. When lightweight materials that are portable and dry assembled site is the outcome of integrating reuse 'C', Gang's prospector's and nomad's approaches. U_5 involves tertiary recycling where the properties are modified according to the intended application as shown in Figure 3.

***Table 6.** The big picture of 'recycling' in architecture and the construction industry.*

<table>
<tr><th colspan="5" rowspan="3">Downcycling / Recycling /Upcycling
(Product and material centric)</th><th colspan="4">Logics, theories and postulates</th></tr>
<tr><th colspan="4">Eco-centric logic and Approach C</th></tr>
<tr><th>Reuse B/C</th><th>Gang's postulates</th><th colspan="2">ROD / resource retention</th></tr>
<tr><td rowspan="3">Tertiary recycling</td><td rowspan="3">Conventional / destructive recycling (feedstock)</td><td colspan="2">Modification of chemical properties (open loop recycling)</td><td rowspan="7">Opportunistic architecture / Developing building materials or applications with recycled content / ROD</td><td rowspan="3">C</td><td rowspan="5">Nomad's and Prospector's approach</td><td colspan="2">New applications through upgrading (U_5)</td></tr>
<tr><td rowspan="2">Original properties as well as with properties that does not fully correspond to the pre-consumed state</td><td>Closed loop recycling</td><td colspan="2">Original application (U_4)</td></tr>
<tr><td rowspan="5">Open loop recycling</td><td colspan="2">Low end application (U_3)</td></tr>
<tr><td rowspan="2">Secondary or physical or mechanical recycling</td><td colspan="2">non-destructive recycling (Deformative / Subtractive/ Additive)</td><td>B</td><td rowspan="4">Functional recycling</td><td rowspan="4">Recontextualization (U_0, U_1, U_2)</td></tr>
<tr><td colspan="2">Conventional / destructive recycling (Feedstock)</td><td>C</td></tr>
<tr><td rowspan="2">Zero recycling /secondary or physical or mechanical recycling</td><td colspan="2" rowspan="2">Direct reuse (or) Non-destructive recycling (Deformative/ Subtractive/ Additive)</td><td rowspan="2">B</td><td>Cook's approach</td></tr>
<tr><td>Prospector's approach</td></tr>
</table>

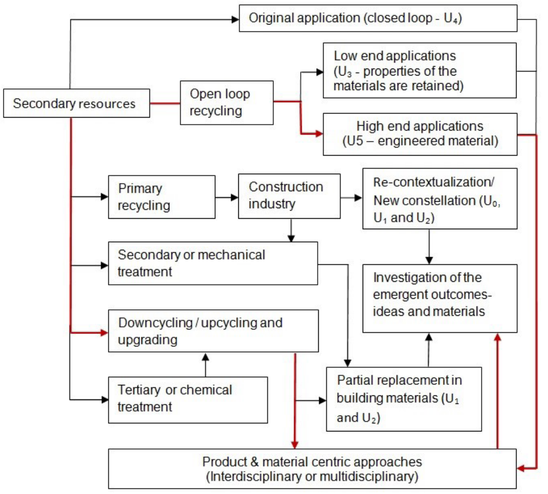

***Figure 3.** An Interpretation on 'recycling' in architecture and construction industry.*

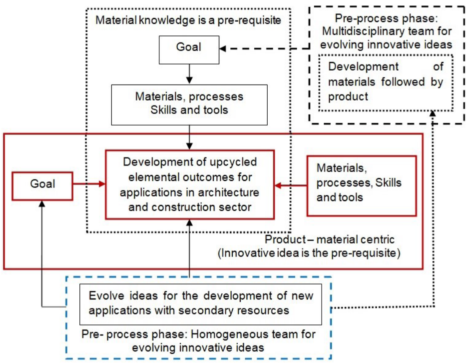

***Figure 4.** The relationship between ROD, product and material centric approaches.*

Downcycling has been identified as a subset of upcycling and also addressed as downgrading. 'Cascading' or 'downgrading' have been the reuse of materials in a degraded form when compared to the pre-consumed state and used for applications lower than the original purpose. This paper has argued that when materials extracted from secondary resources especially from various domains other than the construction sector retain properties that do not fully correspond to the pre-consumed state but used for developing low end applications in construction fall under U_3.

The relationships between recycling, upcycling and upgrading have been interpreted, interrelated with the postulates, logics and approaches framed in architectural domain as in Table 6. Functional recycling or re-contextualization that include U_0, U_1 and U_2 fall under cook's and prospector's approaches and categorized as zero or secondary or physical or mechanical recycling, adopting the ideals of open loop recycling. Tertiary recycling that involve the modification of chemical properties that does not fully correspond to the pre-consumed state for the original or a different purpose in an altogether different domain has been recognized as closed and open loop recycling respectively.

The utilization of secondary building materials or resources from domains other than the construction industry requires either interdisciplinary or multidisciplinary efforts adopting the principles of opportunistic architecture and ROD. However, in today's context, there is an ultimate need to utilize secondary resources from domains other than the construction sector. With this as the focus, this article has mapped a direction to utilise such secondary resources in architecture and construction sector as shown in Figure 4.

In Figure 4, 'material centric' and 'product centric' approaches are mapped. When the approaches are 'material centric' and 'product centric', the investigation begins with the materials and ideas respectively. It is observed that when upcycling the material is the focus, multidisciplinary team is needed for developing ideas. However, a homogeneous team is needed to evolve innovative ideas initially followed by the multidisciplinary team while investigating the secondary resources comes later.

This article has contributed to the existing knowledge in two directions. As already discussed, six degrees of upcycling have been deciphered falling under the classes Repurpose (R_6) and Recycle (R_7). Secondly, this paper has reinstated the need for 'pre-process phase' in both the 'material and product centric' approaches. Further, diverse ways of exploring the 'pre – process phase' to evolve and develop unique ideas and outcomes with secondary resources from domains other than construction sector shall be investigated with homogeneous and heterogeneous teams depending upon the priority.

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