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A COMPREHENSIVE OVERVIEW OF THE REFORMATION OF ANALYZING AND DESIGNING REINFORCED CONCRETE STRUCTURES

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ABSTRACT

Academics and enterprises believe that reinforced concrete (RC) structural design reduces buildings' environmental impact. These buildings must not harm their ecosystems. Eco-friendly buildings are needed. Concrete and steel-reinforced RC buildings are cutting-edge. We're here to help. The study's main questions and consequences are unanswered. Totally ignored. Computational approaches simplify eco-friendly RC structure design. Global influence. This maximizes Earth's resources. This method improves environmental-effects-sensitive RC structure computational design. We wanted eco-friendliness. It's finished. This study anticipates architectural design optimization. This tool is useful for architects. This study examines structure layout improvements. Building design can accomplish both. In the introduction, RC structure design must be holistic and interdisciplinary. Start here. Must have. Showcase the latest RC building technology. Time precedes this query. This website explains how to design green buildings. We investigate every new field. Optimizing RC buildings requires additional quantitative and qualitative study. Structural design specialists in academia and industry can use computational tools and optimization methods to solve RC design problems. RC structure design requires combining two related aspects. This can help students and structural designers use green construction strategies. Using this data, architects may design greener. Inspecting RC construction parts does this. Combining essential RC structural design principles could achieve this.

Introduction

Steel and concrete support RC buildings. RC structures no longer utilize concrete or steel reinforcement. Sustainable computational advances for RC structures. The developed world studied sustainability (Ding, 2008). Structures reduce greenhouse gas emissions and embodied energy. Low-carbon, energy-efficient buildings are modeled in Sepehri et al. (2020). The materials, internal temperatures, and structural systems of RC buildings that are energy efficient have all been enhanced (Kofoworola and Gheewala, 2008; Gan et al., 2019b). Plain concrete's CO2 embedment increases from 100 to 450 kg/m3 when SCM and strength are added (Gan et al., 2019a). Specifically, 0.13 kg CO2-e/kg regular concrete and 0.24 kg 2% steel-reinforced concrete were used by Harrison et al. in 2010. Carbon emissions from low-rise to high-rise residential and commercial RC buildings can be reduced by the use of parametric design (Foraboschi et al., 2014; Gan, 2019a). Green design Computational and parametric design optimized embedded carbon emissions. The RC frame, beams, columns, foundations, floor slabs, shear walls, and retaining walls were environmentally designed. Recent proposals for environmentally friendly reinforced concrete (RC) buildings and infrastructure have combined cost parameter with optimization of material consumption (Eleftheriadis et al., 2018b) and environmental performance of RC structures (Eleftheriadis, 2017; Yousuf, 2017). Early environmental sustainability strategies are structural. Chutani and Singh (2018). Early-stage construction designers and constructors automatically optimize material usage. Savings benefit AEC stakeholders. Using cheaper materials lowered RC building weight (Prakash et al., 1988; Kanagasundaram and Karihaloo, 1991b). Computer algorithms that automatically decrease steel reinforcing material in RC frame designs save a lot of material (Govindaraj and Ramasamy, 2007; Mangal and Cheng, 2018). Kirsch (1983) advised lowering RC structural steel reinforcing to save money. Structural design optimization parameters are growing exponentially, necessitating automation. Many review articles outline the newest optimization technologies for RC structure design for environmental efficiency due to its widespread application. Sarma and Adeli (1998) designed cheap RC frames, components, and infrastructure. 2011 Fragiadakis and Lagaros examined earthquake-resistant, cost-effective structural optimization framework design formulations. Yang et al. (2016) briefly discussed civil engineering design metaheuristics. Cohn and Dinovitzer (1994) and Salehi and Burgueno (2018) investigated artificial intelligence in structural design optimization. BIM-based green building evaluation, embodied carbon optimization, and sustainability share a paradigm. Embodied carbon and structural engineering computer methods dominate RC structural design optimization studies. This essay covers computationally driven detailed design for sustainable RC structure design literature. Steel reinforcement reduction optimization for sustainable RC structure design is understudied, but crucial. Building professionals have focused on computationally driven, all-encompassing sustainable design optimization since steel reinforcing is expensive. Thus, this work critically evaluates the literature on automated detailed design optimization for RC structure environmental efficiency. Database keywords generated four research topics. These studies include a wide range of optimization objectives from previous work, offering a more full understanding of the area, future directions, and state of the art. Studies are covered here. Studying RC constructions' costs, material efficiency, and ecological sustainability may help.

This review format follows. Section 2 covers our extensive literature review and sources. The third section addresses long-term, geographical, and adaptive regional changes. Section 3 outlines research goals, optimization strategies, and computational methods. Chapter 4 outlines research needs and next steps.

Methodology

In this study, we use a comprehensive approach to support a comprehensive overview of the state-of-the-art research applied to the literature evaluation on the topic of the optimization of the design of RC structural details from 1974 (when the first relevant research article was identified) to 2018. This study begins in 1974, when the earliest relevant journal paper was found, and continues up to the present day. The first piece of evidence relevant to this investigation was uncovered in 1974, and the investigation will continue until 2018. The inquiry begins in 1974, when the earliest relevant item of literature was uncovered, and continues up to the present day, 2018. This section includes an illustrated how-to guide that dissects the process of retrieving literary works from digital databases into its constituent parts and presents them in a straightforward fashion. Indexing, categorization, and statistical analysis are all used to further refine the findings of this procedure.

Literature retrieval

Search engines like Google Scholar and databases like Scopus, Taylor & Francis, the ASCE Library, Willey Online Library, Emerald, Science Direct, and the Web of Sciences (WoS) are employed in the literature retrieval process based on the topic of RC structural detailed design optimization. The method also depends on research into improving the layout of RC support elements. Some of the terms that were used to find relevant articles were: embedded carbon optimization; life cycle cost; sustainable design; cost optimization; optimal design; minimum cost; steel reinforcement; and RC or rein-forced concrete structures. These search terms should bring up the majority of the articles on this site.

Following that, the collection of samples was carried out by looking for and organizing a variety of research articles throughout the course of a few iterations of the process. After completing a search using keywords, the portfolio of more than 450 original research articles, reviews, conference proceedings, book chapters, and published theses was assembled. After the articles had been received, they were first categorized according to the categories of documents they represented, and then they were put through a second round of analysis to evaluate whether or not they met the requirements for the subject matter inclusion criteria. In the course of conducting the content analysis, the result uncovered a total of 348 research articles taken from more than 86 different journals. These articles can now be used in the process of additional refining and categorization as they are accessible. The subsequent phase involved reading and thoroughly analyzing research articles with the intention of establishing whether or not the articles that had been selected were suitable for the purposes of the current study or not. In the end, the selected articles were organized into their appropriate categories, which were established based on the objectives of the research, so that additional studies might be carried out in the future.

Results and discussion

General trends

This was an easy conclusion to draw, given the rise in the quantity of pieces in print over the past few decades was plain to notice. The fact that 340 articles from various publications were collected demonstrates this to be accurate. Since both academia and industry are becoming increasingly interested in transdisciplinary optimization of designs, it seems likely that the number of publications in this area will rise in the future. In other words, there is a strong possibility that the number of publications will rise in the future as a result of the increasing attention paid to complete design optimization in academia and business. When looking at the total articles divided down by category, material efficiency, commonly known as C1, receives the least attention, accounting for only 32 studies (9%). This is due to the fact that C1 is another name for material efficiency. However, throughout the course of the research, the most articles focused on material and cost efficiency, sometimes known as. This totaled 232 pieces, or 67% of the total. In total, C3 and C4 are responsible for 42 and 40 published articles (12% and 10% of the total, respectively). On the other side, C2 is to blame for every published paper. Complete design optimization of RC structures was a popular topic for academic publications over the time period covered by the studied. The research led to the discovery of this data.

The number of articles published annually in the field of RC structural detailing design optimization study has increased from two in 2009 to four this year. C1's publication pattern mirrors the general trend in studies aimed at optimizing the design of RC structures. As can be seen in Fig. 4(b), the general tendency of this category of study themes follows the global rising trend except for the years 2010-2011 and 2012-2013, which indicates a notable growing interest of current studies. Furthermore, the overall trend of this research theme area declined between 2010-2011 and 2012-2013. However, the overall trajectory of this research issue area is consistent with the expanding pattern observed worldwide. The primary goal of the studies conducted during the comprehensive design phase for RC structures was to find methods to reduce the necessary quantity of concrete and steel reinforcement. This involved minimizing the rebar waste rate in the detailed design of RC structures (Porwal and Hewage, 2012), automating the optimization of steel reinforcement in RC structures (Mangal and Cheng, 2018), and optimizing the lowest weight of RC structures (Oh et al., 2016). Multiple studies (Oh et al., 2016; Mangal and Cheng, 2018; Porwal and Hewage, 2012) support this theory. The regular distribution of C2 publications holds true from its inception in 1977 with a single article to its present day with seventeen articles. In contrast to the current year's total of 17, only one article was published at the time. The majority of the total number of articles (232) may be attributed to this type of research topic out of the whole portfolio of 348 articles. The trend of this study theme is followed by a big increase due to the vast number of works that have focused on the reduction of associated expenses and the materials that are employed throughout the process of optimizing the detailing design of RC structures. Included in this total are the costs of labor/formwork, material production, transport, and set-up. The expense of steel reinforcement is included as well. These costs can be reduced by incorporating a variety of optimization strategies into RC structures (Chutani and Singh, 2017; Reddy et al., 1993). Life cycle carbon emissions and life cycle cost analysis were recommended for bridge maintenance considering environmental consequences in the 21st century (Itoh et al., 2001), attracting a large number of scholars. This demonstrated the optimization of RC structures with environmental sustainability factors taken into account. Most studies that were filed under these categories (C3, C4) had ecological sustainability as one of their primary motivations for doing research. In order for researchers to incorporate various components of the design into their studies at various phases, it is crucial to give researchers with short insights about the technique by which specific design features were incorporated. To achieve this goal, it is necessary to supply researchers with concise insights on the manner in which various aspects of the design were implemented. Optimization of RC structures has previously been broken down into manageable steps, which have been presented in the form of research themes. This development is already under way. This structure begins at the ground floor and ascends to the penthouse. Initially, RC structural design was created using traditional approaches, which often resulted in solutions that were not only incorrect but also time-consuming and laborious (Mangal and Cheng, 2018). Initially, RC structural design was developed using conventional techniques. Since incorporating computers into structural analysis and design, designers' focus has shifted to the creation of lightweight structures that retain strength and durability.(Kaveh and Behnam, 2013) Items that are either almost wholly or completely within one's financial limits. The use of optimization strategies allowed for the consideration of all of these factors. To optimize the design process and achieve the intended outcomes, a number of optimization approaches were integrated into the design process. The incorporation of environmental elements into the design process has made contemporary optimization efforts in RC structural design more eco-friendly and long-lasting.

Geographical trends

More funding from the government and private industry for academics in the field may account for the larger number of publications in the field (Olawumi et al., 2017). In Fig. 5(a), we can see a general trend in how the gathered literature is broken down by region. Terms like "geographical scope" and "research origin" are used by the authors in (Neto et al., 2016; Olawumi et al., 2017) to describe methods similar to those used here in order to map the existing research. Growth in Asia and Europe over the past few decades is consistent with the increased number of publications originating in those regions. This suggests that they are becoming more concerned with minimizing the financial, material, and ecological impacts of RC structure construction. The number of articles retrieved from North American research libraries was second highest. The first academic paper on engineering optimization was written by Northern Irish citizens and published in 1974 (Bond, 1974). The United Kingdom and European countries like Spain, Greece, Italy, Slovenia, Austria, Turkey, and Portugal are prominent in every area of study. India, the People's Republic of China, South Korea, Hong Kong, Japan, Taiwan, and Thailand are only few of the countries that have been cited as taking part in the research operations surrounding the topic at hand. Australia also boasts a substantial amount of research in all four major academic disciplines. The quantity of scholarly works produced by Iranian research centers varied widely throughout the four areas of inquiry. Scientists in seismically active countries like China, South Korea, and Spain devote more time to exploring C4 as a research issue. This is just one instance when factors like geography and environmental seismicity shaped the course of study. Many countries' regional design guidelines for RC buildings already incorporate environmental issues into the earliest stages of planning, construction procurement, and life cycle performance.

Regional standardization trends

Most research obtained on RC structural design optimization have followed regional criteria to assure the essential building performance. These constraints on the optimization process led to more practical results. During the preliminary design phase, RC structural design requirements may be specified by regional structural institutes or expert government organizations. The American Concrete Institute (ACI) Codes for Concrete (Shahnewaz et al., 2016), the European Construction Code (Eurocodes 2) (Quaranta et al., 2014), the Indian Standards (IS-456) (Govindaraj and Ramasamy, 2005), the Australian Codes (Kanagasundaram and Karihaloo, 1991a), and the Spanish Structural Concrete Code (E) are the most frequently used international building codes. The majority of studies have followed the ACI guidelines for improving RC building construction. This is a reflection of the trend toward regional design standards in research, which has led to a rise in the number of publications categorized under those themes. To avoid any ambiguity, only the most often used components from each region's design requirements have been included. Among the 124 ACI-compliant articles are 11 papers from the C1 research theme, 98 papers from the C2 theme, 1 paper from the C3 theme, and 14 papers from the C4 theme. The fact that the central government in some countries lacks the authority to mandate adherence to regional standards for structural concrete and related materials is a significant barrier to implementation. You get access to the vast majority of literature developed on the C4 research theme.

code from 14 different sources (ACI, Spain, and the EU) and get it all working together. In the United States, the rule applies to all types of buildings. However, in other countries, the area of coverage varies greatly. For instance, the majority of the emphasis in the Korean Energy Standards for buildings is placed on extremely energy-intensive megastructures. Based on the available information, it is clear that environmental sustainability considerations are included in the ACI, the Spanish Codes, the Eurocodes, and the Korean Standards and must be incorporated into the detailed structural design of any building located in a particularly vulnerable part of the world. Therefore, the performance of both new and older RC buildings would increase over time.

Discussion

Optimization of RC detailed design

In-depth coverage of the four most important factors in optimizing the detailed design of RC structures is provided here: It is important to understand four key aspects of design optimization: (1) its breadth, (2) its depth, (3) its methods, and (4) its computational tools for tackling challenges. Each of these topics is treated as a separate section of this review, and examples and references from the recovered state-of-the-art literature are supplied to explain them.

Design optimization scope

In this section, we'll go through some of the most common optimization criteria and approaches used in prior research on RC structure detailed design optimization. It is crucial to define the optimization's scope and aim through the objective function and subsequent solution approach. There are many other types of RC structures and components that can be taken into account, such as orientation-wise (horizontal and vertical com- ponents), super-structure and sub-structure, flexural and shear, load-bearing, etc. Researchers have taken an interest in the relative design of either individual components or whole structures because of the potential for variation in shape, size, reinforcement scheme, and configurations due to variations in stress and environmental circumstances. Figure 7 graphically displays the overarching pattern of using various RC parts for deep design optimization across all four study topics. 152 papers advanced RC frame designs. Beams, columns, slabs, foundations, shear walls, and rectangular sections have been researched more than underground utilities, subways, elevator shafts, membranes, circular, spiral, and irregular sections. Infrastructure, low-rise RC frame, and high-rise structures were investigated (Aldwaik and Adeli, 2014). Two-dimensional RC structural geometries outperform three-dimensional ones. Material interaction in RC construction includes design optimization for steel-concrete adhesion and recycled materials (Papavasileiou and Charmpis, 2016). Seismic RC constructions require high-quality materials (Khatibinia et al., 2015). Since construction materials serve different purposes throughout the structure's life cycle, the optimization model must consider cost and embodied energy trade-offs (Eleftheriadis et al., 2018b). (Seara-Paz, 2014). In seismic and reliability-based multi-objective design optimization of RC structures and infrastructure, decision makers care about steel reinforcement and concrete corrosion and adhesion (Sajedi et al., 2017).
Size optimization (Choi et al., 2017), shape optimization (Rath et al., 1999), and topology optimization (Aydn and Ayvaz, 2010) are all common tasks in the context of optimizing a single RC component. It is worth noting that when big constructions with repeated individual components are at stake, sizing optimization becomes a primary concern, and the optimal geometries for the cross-sections of individual components become an area of focus. When searching for the best possible shape, structures and/or their parts may be transformed. Reducing the quantity of materials for lightweight buildings and finding the ideal positions for certain components for targeted performance are two possible goals for component optimization. Topology optimization minimizes resources expended where they are not required to produce the desired structural performance in isolated parts. Various parts illustrate various arrangements of reinforcing bars.
This review study compiles data from prior studies about various RC structural components based on the various configurations of steel reinforcement and the complexity of the reinforcement configuration. It's worth noting that no articles about problems with bridges, retaining walls, or foundations were retrieved from the C1 subject. These parts have elaborate reinforcement configurations that could be used in subsequent investigations of their particular research areas. Furthermore, the optimization of RC beams and shear walls has not yet taken into account the environmental efficiency element in its entirety. The primary goal of this statistical scope is to provide a transparent indication of the study territory in which many unresolved RC structural components might be optimally designed.

Formulation of optimal design problem

In order to create a problem, one must identify the scope of the search, the design variables, and the constraints that must be met. The desired result of a minimization or maximization optimization issue is expressed numerically as the problem's goal. Its intended purpose could be single or multifaceted, depending on the specifics of its implementation. Because the optimization of the finer points of the design involves several conflicting criteria, recent research has focused on multi-objective issues, where trade-offs or competition between many parameters are considered. For such situations with many objectives and nonlinear relationships, metaheuristic algorithms are widely employed in search of optimal solutions. Complex structural engineering problems are best tackled by modern metaheuristic algorithms that prioritize high processing speeds and robust programming (S'anchez-Olivares and Toma's, 2017). While some studies have focused on incorporating numerous objectives into a single one (Oh et al., 2017), others have taken into account economical and ecological considerations when defining goals (Ferreiro-Cabello et al., 2018). An objective method for designing rectangular cross-sections of RC continuous beams to minimize cost and embodied energy is presented by Yeo and Gabbai (2011). We just talked about the beam's depth, height, longitudinal reinforcement, and shear reinforcement; not the rebar's positioning or diameter. The design space was reduced by splitting continuous and discrete variables up into their own categories.

Issue formulation requires evaluating the differences between constraints and objective functions to locate the optimal solutions in the search space by establishing an objective function that balances desired performance with applicable restrictions. It has been used as a penalty function in slab reinforcement structural optimization (Eleftheriadis et al., 2018c) and as a constraint in site-specific steel reinforcement procurement (Mangal and Cheng, 2018). The study's main goal was to automate the congestion and complexity assessment of RC beams with steel reinforcing bars (Navon et al., 2000). In order to perceive optimal design solutions, one needs a model of the objective function that describes the desired qualities, as well as the values of the most important factors as variables. For instance, although concrete, steel reinforcement, and formwork were all included in the cost function, the design variables were only tied to detailed reinforcement because of the greater variable impact this item had on the total cost (Rajeev & Krishnamoorthy, 1998). The exact quantity of reinforcement was difficult to calculate until after the detailing was complete, therefore this formulation was created to account for that. The price of concrete and formwork could be simply determined if the precise dimensions were known.

Project owners and other stakeholders place a premium on cost efficiency in the architectural, engineering, and construction (AEC) industry. Previous studies have focused on optimizing steel reinforcement to reduce its weight, associated costs, and total construction cost; this study elucidates the steps involved in including the appropriate design parameters and elements when defining the goals for RC design. Importantly, objective functions should be formulated so that they can satisfy most of the requirements while assigning less weight to trade-offs. Porwal and Hewage (2012) created an objective function that modifies the building's layout according to the available lengths of rebar to cut down on the amount of rebar that is wasted during construction. Although the expense of rebar loss control was reduced, the building's aesthetics were sacrificed. However, in regions with higher land costs, like Hong Kong, the problem could be solved more efficiently by treating the layout plan as a constrained parameter. Many noteworthy skyscrapers have had their target function composition optimized to reduce the building's weight and, by extension, the building's overall structural cost (Chan and Wang, 2005, 2006; Huang et al., 2011). When this occurs, the technical and economic performance of RC structures can benefit greatly from the formulation of the objective function.

An additional common criterion is the assessment of the whole cost of ownership, from initial conception through eventual demolition. Since the cost is inextricably tied to global warming, Yepes et al. (2008, 2012) devised a mental technique for developing a multi-objective function for structural concerns that accounts for the tensions between competing goals. In the case of RC I-beams, mathematical modeling was used to simultaneously optimize three goal functions: economic cost, carbon emissions, and service life. Minimizing steel reinforcing parameters and exploring major improvements utilizing a BIM-based life cycle carbon assessment technique were among the environmental sustainability targets pursued during the RC detailed structural design (Eleftheriadis et al., 2018b). Policies have been established, however it is essential that they be adhered to. These regulations connect sustainability and environmental performance goals with early stage building planning. Because of this, there is a greater need than ever before for an integrated approach in this field that takes into consideration future environmental goals at both the structural unit level and the detailed design level.

Correct formulation of the objective function(s) and careful selection of design variables are crucial to the success of an optimization study for comprehensive RC structural design. Earlier studies typically focused on minimizing total weight, cost, and seismic designs with merely optimization methodologies, whereas more recent ones highlight the use of cutting-edge technologies like building information modeling (BIM).

Optimization techniques and methods

Different optimization algorithms exist for dealing with difficult, NP-hard, and average-sized structural engineering problems, and their overarching purpose is to find the best viable design solutions in either bounded or un- bounded domains (Dede et al., 2018). Early efforts were limited to handling only the smallest-scale structural design optimization problems because there were no effective and trustworthy optimization methods available until the 1980s (Vanderplaats, 1993). Engineers have long used optimization methods like Differential Evolution (DE) (Quaranta et al., 2014), Linear Programming (LP; Balling and Yao, 1997), Non-linear Programming (NLP; Colin and MacRae, 1984), and Sequential Linear Programming (SLP; Kanagasundaram and Karihaloo, 1990; 1991a,b). Particle swarm optimization, ant colony optimization, simulated annealing, and artificial bee colony (ABC) (Jahjoui) are more examples. Other studies have used more general numerical methods to calculate the optimal quantities of steel reinforcement to use in RC components; these studies include those by Ferreira et al. (2003), MacRae and Cohn (1987), Colin and MacRae (1984), etc. The computation for actual optimal solutions is quite fast because these studies have relatively basic objective functions and only a little search space to consider. The specifics of the situation dictate the optimization strategy employed. For instance, deterministic optimization techniques that adapt to each new situation and seek to maximize their own benefit at the expense of others are excessively greedy. Meta-heuristic optimization methods, on the other hand, are widely accepted because of their ability to solve difficult NP-hard problems without revealing their inner workings to the user. Since optimizing the current detailing design of RC structures is a challenging NP-hard issue due to the enormous number of potential options, metaheuristic optimization techniques are commonly used in civil and structural engineering. The numerical distinction between the two optimization approaches is illustrated in Fig. 8. Because of its flexibility, GA has become one of the most often used metaheuristic optimization methods. As can be seen in the graph, whereas there are 33 articles dealing with HS optimization, 87 are dedicated to GA.

Natural selection is mimicked by random mutations in the Genetic Algorithm (GA), a metaheuristic algorithm with evolutionary foundations. It efficiently manages non-linear problems with discontinuities and many local minima by evolving a population of optimal solutions using a binary representation of chromosomes with additional crossover and mutation operators. This method has been used to optimize the steel reinforcement quantity, rebar layout configuration, sustainable detailing design of steel reinforcement, and rebar waste rate in RC structural designs. Since the RC structural design optimization problem is computationally infeasible, GA is often employed to do a thorough search of the search space and produce optimal solutions. Wang et al. (2005b) used a multi-objective genetic algorithm to offer a set of pareto-optimal solutions for green building design. There are a lot of upsides to using this method, such as its short learning curve, generalizability, speed, and variety of possible results. The GA's modular structure has inspired a number of adaptations that can be used to a diverse set of circumstances. Recently published works have made use of one of the most popular variants of (Eleftheriadis et al., 2018a, 2018c).

Developed by Deb (Deb and Sundar, 2006), Non-dominated-and-crowding Sorting Genetic Algorithm II (NSGA-II) is a multi-objective genetic algorithm. NSGA-II is well-known for its ability to successfully approach the Pareto front in difficult computational tasks, making it one of the most popular and commonly used multi-objective optimization techniques. Combining the GA with another suitable algorithm, like the GA-HJ does (Sahab et al., 2005), can further improve the GA's convergence. Nondeterministic approaches like this one also make use of a number of stochastic procedures and operations, but they don't promise to lead you to the most accurate conclusions. When applied to large and complex situations, the GA may incur extra processing costs due to the iterative nature of the fitness function evaluation.

Harmony Search (HS) is an optimization method that generates optimal solutions by recombining the values of the variables being optimized for based on the path deviation from regionally averaged values. Its natural nature sets it apart from other optimization approaches, and it is inspired by the strategies employed by musicians in their pursuit of greater harmony (Geem et al., 2001). In most cases, the HS algorithm outperforms competing methods because of its ability to replace bad solutions with good solution decision variables at each iteration (Akin and Saka, 2015). This method is strong, efficient, and reliable, thus recent improvements should boost its effectiveness in deployment. Bekdas and Nigdeli (2017) modified this method with random search phases to find the ideal detailed design of RC frames at the lowest possible cost. The improved version can be used to investigate structural engineering concerns and is more usable in general.

The performance of this algorithm is bound by the performance of evolution strategies (Weyland, 2010), and (1) it is not a really unique method separate from its metaphor. The capability to seek for local minima/maxima is limited, demanding multiple iterations; nevertheless, it does permit both continuous and discrete variables (such as the diameters of steel reinforcing bars).

The Simulated Annealing (SA) approach gradually deviates returned solutions from their existing placements over the course of subsequent generations to increase the possibility of recovering solutions and to update the pareto list towards optimum values. This iterative method is useful for solving combinatorial optimization issues with a discrete search space. Michalek et al. (2002) used GA and SA to discover a global solution to an optimization problem in architectural layout design that involved a large number of possible component combinations. Yepes et al. (2008) applied this strategy to optimize the design of RC earth-retaining walls economically while still achieving performance requirements. It shows that a dynamic calibration is required and that its performance improves as more variables are modified at each iteration. Integrating rigorously derived optimality criteria (OC) (Li et al., 2010a), this approach allows for the structural optimum design of RC buildings under severe multi-load scenarios. It was demonstrated beyond a shadow of a doubt that the optimal performance requirements for the structure (i.e., both strength and stiffness optimum design) aimed to achieve optimal solutions in a malleable practical zone. In cases when many objectives need to be balanced during optimization, the SA has proven to be the method of choice (Paya et al., 2006, 2008). Although this method has several advantages, it comes at a significant computational cost without offering an upper bound.

Based on their current, local best, and global best positions, Particle Swarm Optimization (PSO) solutions gradually adjust their position for the following iteration. From the current state of solutions, optimal solutions can be constructed by applying the provided velocity, mass, and acceleration. The cooperative behaviors of fish schools and bird flocks, in which individuals are continually relocating within a high-dimensional search space (Zhu, 2008), provided the primary inspiration for our method. An optimization search strategy can only be committed to once a set of random answers has been fine-tuned in this fashion.

Descent Local Search may take more than n time to find a solution if the optimizer is sensitive to generational updates. In comparison to GA and other metaheuristic algorithms, this method dramatically reduces computational time while maintaining or improving solution quality. It is also demonstrated that the modified algorithm improves upon the convergence towards optimal solutions over the traditional PSO method. This technique can be employed in the routine procedures of structural engineering, and it has a lower computing cost than other optimization approaches. There are some drawbacks to using PSO for optimizing RC structures, despite its effectiveness. For example, it can be difficult to identify the initial design parameters, and it can get stuck in local minima when calculating big problems.

The search space for the problem is limited in Nonlinear Programming (NLP), but there are many potential actions that can be taken to satisfy the nonlinear objectives. Almost majority of the difficult design problems that arise in structural engineering details involve nonlinear interactions for minimizing or optimizing the aim function(s). Most previous research has concentrated on limiting the nonlinear interactions between several structural performance parameters to reach optimal cost, drift, stiffness, and weight design solutions. A Mixed Integer Nonlinear Programming (MINLP) paradigm was employed when nonlinear constraints and goal functions were present with discrete and continuous design variables. To identify the optimal design of concrete buildings at the lowest possible cost, the authors of (Guerra et al., 2011) reconstructed the added nonlinear constraints and investigated the application of MINLP. When dealing with a large number of possible decisions, however, MINLP approaches can take significantly longer to compute than other methods.

Several new optimization solutions have been presented recently, in addition to the aforementioned methods. Here are some examples: Big- Bang Big-Crunch (BB-BC; Camp and Akin, 2012); Cuckoo Search Optimization (CSO; Gandhi et al., 2017); Glowworm Swarm Opti- mization (GSO; Yepes et al., 2015a,b); Charged System Search (CSS; Kaveh and Behnam, 2013); Cuckoo Search Optimization (CSO) has not been investigated for any study area other than cost efficiency, as seen in Figure 8. This is only one example of how not all targets in the field have yet included the most recent optimization approaches. This optimization technique, like other state-of-the-art approaches, has room to grow. Table 2 summarizes useful guidance that constitutes the ideal solution to the RC structural design optimization problem. In addition, it can provide a balanced assessment of the merits and downsides of several algorithms for fixing the problem at hand. The current study demonstrates that hybrid optimization methodologies efficiently arrive at optimal solutions for computationally hard and moderately large structural design optimization issues.

Computational tools

RC structures are parametrially modeled early in design utilizing structural analysis, simulation, and visualization software. Structural design and analysis computations were tedious and error-prone before computers. Trial-and-error learning completed these procedures (Kaveh and Behnam, 2013). Engineers and architects may develop and analyze structures faster and more accurately using computers and other technologies. Before computers, structural engineers employed ETABS and SAP for building design and analysis. Cutting-edge structural design optimization. Porwal and Hewage (2012) used Autodesk Revit BIM and 1D cutting waste-optimization to interpret their findings. Revit optimized the building's height, width, and rebar diameter. Optimization calculations require proper software. Steel reinforcement scheme data compilation begins with a BIM environment. ETABS structural analysis yields reinforcement bar optimization data.
Previous software failed.

Lack of automation, interoperability challenges (Arayici et al., 2018), structural practitioner inventiveness (Rolvink et al., 2014), and semantic 3D visualization up to BIM level of detailing make complex engineering problems difficult to tackle. To automate and personalize RC structure design optimization, software packages often incorporate APIs (Oti et al., 2016). RSA can assess and optimize steel reinforcement using Autodesk Revit's API. Other steel reinforcement detailed design optimization and automation works (Eleftheriadis et al., 2018c; Mangal and Cheng, 2018) provide API links between computational tools. Engineers designed the structural analysis program's GUI. These applications maximize structural engineer conceptual designs. Pre-merged optimization improves RC structural design optimization computational methodologies. Some RC structural design optimization software requires much interpretation and understanding. Computer-based conceptual design optimization gives structural designers more engineering issue options.
Table 3 compares RC structural optimization computational approaches. Programs from any field can help optimize RC structure design. Popular software categories:

Revit, 3D Studio Max, Tekla Structures, ArchiCAD, MicroStation, and Vectorworks are BIM software.
CSi ETABS, SAP, SAFE, RSA, STAAD.Pro, ANSYS, ADINA, and Tekla Structural Designer analyze and design structures.
Autodesk Civil3D, CSi Bridge, Infraworks, Civil Designer, and others help create and manage infrastructure.

APIs help developers and designers personalize computational tools. It links incompatible programs. Current research demonstrates that merging a custom API with an existing software package improves results. Despite many new computational tools for full design optimization of RC structures, most academics, with a few notable exceptions, still use the old, tried-and-true software. Commercial computational tools simulate after specifying an objective function. APIs connect software systems when commercial solutions fail (Schlueter & Thesseling, 2009).

Clash free steel reinforcement optimization

Reinforcing structural components with several bar kinds at different topologies is tricky. Beams and shear walls need distinct steel reinforcement. Structural components are load-bearing and contain complex reinforcing arrangements. Beams are flexural, shear walls and columns are axial. Torsional reinforcement is needed to distribute loads from moment, torsion, and combination effects. For clash-free steel reinforcement optimization, these technical parameters affect optimal design formulation, variable definition, design restrictions, and optimization searching algorithm. Rebars may clash at beam-column intersections during steel reinforcement design optimization.
Identifying and resolving these incompatibilities early in detailed design improves rebar constructability. Based on this breach, further research may explore more rationales to optimize steel reinforcement arrangement designs without crossing rebars of varied geometries. Combining rebar sizes can maximize weight but increase complexity and constructability (Eleftheriadis et al., 2018c).
Clash detection during rebar detailed design optimization can instantly address spatial clashes at RC component joints. Mangal et al. (2017) resolved analytical rebar conflicts at column-beam junctions after significant steel reinforcement design optimization. BIM automatically fixed these rebar conflicts. Multi agent-based BIM-based automated rebar path planning was explored to avoid column beam joint clashes (Liu et al.,

2018). Despite these methods, efficient collision resolution methods are needed to achieve a clash-free rebar layout at complex connections during early rebar detailing design. Rebar setups and conflicts can be exacerbated by RC component cross-sectional geometry. Future research will enhance rebar details design for clear clash-free spacing between rebars at such connections. Early design simulations can mimic the installation sequence of many-diameter rebars for complex layouts to ensure smooth execution. This may be cheaper for large, intricate RC structures with several project parties participating in detailed design. BIM-technology can visualize and interpret clash-free design syntheses by examining the feasibility of numerous clash resolution alternatives by exploring object spatial connectedness within joints. VR, AR, and MR technologies should help BIM models of rebar layout at RC component joints automatically detect and resolve rebar clashes. Design element capabilities can automatically identify clashes, but clash resolution requires visual aid. Future studies can automate early collision detection and resolution.

Multi-objective optimization

To improve RC structure design optimization, integrate environmental sustainability issues. Instead of structural performance analysis, future studies may use associative platforms for rebar detailed design optimization. Steel reinforcement design optimization with sustainability integration can enable lifelong environmental efficiency from manufacture to fabrication, transportation, rocurement, service, destruction, and recycle (Puskas and MOGA, 2015). Several studies suggested material reuse, structural form, structural system, and component geometries to reduce environmental effect.

Steel reinforcement detailed design optimization with cost and environmental sustainability would become a multi-objective/disciplinary optimization issue with a good trade-off between design variables that requires sophisticated mathematical formulation and method selection. RC structure designers often set long-term economic and environmental performance targets. A multi-objective issue with reinforcing corrosion, maintenance, repair, retrofit, and replacement costs may be needed for an economical design. Future studies should organize components and variables by kind and performance and establish the best optimization technique. Alternative steel reinforcing materials can increase the lifespan of RC structures by providing high-strength, cost-effective, and sustainable performance. If used sparingly, some steel alloys can lessen environmental impact. Future design studies could incorporate low-cost and low-amount steel reinforcement to improve environmental efficiency. Steel is more environmental than FRP reinforcement (Katz, 2004). Homogenous flowable fiber concrete's low flexural performance necessitates appropriate fiber orientation (Grünewald et al., 2012). Incorrect fiber alignment renders RC constructions more prone to multiple cracking, which reduces their mechanical performance (Yıldırım et al., 2015). Thus, environmental and technical investigations can assess steel reinforcing components. Future studies can vary material alternatives in steel reinforcement design optimization since these alternatives can change problem formulation at detailed designing stage. Recent economic studies focus on material aspects and alternatives. Thus, future studies may include material properties in optimization objectives and examine how they effect RC design optimization. Smart reinforcement, carbon fiber reinforcement, shape memory alloy reinforcement, and self-healing concrete can forecast the RC structure's dependability and performance during early rebar detailing.

Design for Manufacturing and Assembly (DfMA) reinforcing detailing concentration

Design for Manufacturing and Assembly (DfMA) has improved AEC design and construction quality. Offsite and prefabricated construction approaches can reduce C&D waste and increase construction productivity (Afzal et al., 2017). This field is not advanced enough to intuitively and automatically assemble prefabricated components with rebars at construction sites. Optimizing DfMA rebar layout and arrangements can boost prefabricated construction productivity. Digital fabrication has improved construction project quality, cost, and efficiency (García de Soto et al., 2018). Structural designers must address rebar factory manufacturability and construction site buildability early on. Rebar detailing design optimization for construction DfMA will be studied more in the future. Manual rebar bending can weaken complex-shaped structural components due to their multiple-bent profile. For DfMA, rebar profile-oriented manufacturing and manufacture require rebar efficient methods. Thus, future study can use BIM technologies and optimization methodologies to automatically design and prepare rebar fabrication information to coordinate prefabricated assemblies. Thus, this method may inspire further research on interoperable systems for digital BIM and digital industry fabrication. This information interchange between platforms will improve steel reinforcement erection constructability and buildability, improving construction project delivery. Future re-searchers can reduce steel reinforcement waste as a raw material for DfMA and affect human resources, time, cost, and environmental competencies.

Instead of rebars, prefabricated RC structural assemblies require steel reinforcement cage manufacture and assembly. Future research may reduce steel reinforcement waste by optimizing rebar networks for better coordination and evaluating the design for manufacture, assembly, remanufacture, and reassembly (DfMARR). Future DfMA approaches must create 5D or higher-dimensional simulation models of rebars for construction projects to determine rebar quantities for prefabrication, installation, and clash identification and resolution. These methods can also analyze sequenced rebar installation time and cost certainty from early design to construction.

Conclusions

The literature on optimization methodologies and the development of optimization tools for RC structural detailed design is summarized in this study. A systematic search of the literature turned up 348 articles from 86 different databases of electronic scientific literature. Articles from the years 1974-2018 were culled for this study.

The gathered literature is statistically and mathematically evaluated to reveal novel approaches to optimizing the design of RC structures.

In research on RC structural detailed design optimizing, four primary study theme areas have emerged: material effectiveness, material and cost effectiveness, materials and ecological effectiveness, and environmentally friendly design effectiveness. These classes were set by the fundamental aims of RC structure optimization. The first class uses several optimization techniques to determine the optimal steel reinforcement quantity for RC buildings and parts, while the second class finds the best way to minimize the cost of building materials. Methods were provided for effectively expressing the design optimization problem, defining design variables, and developing constraints, all of which are essential for a complete grasp of the material. Many different optimization strategies were tried out for the detailed design optimization problem.

Finally, possibilities for the future multi-disciplinary optimization of specific design of RC structures were found, as well as general hurdles and limits, from this extensive study. Some of the gaps that have been discovered include a PBD method, a whole frame structure for detailing design optimization of steel reinforcement, and the detection and resolution of joint clashes. Steel reinforcement detailing for complex and irregular geometrical RC structures, improved optimization techniques, and taking DfMA into account during steel reinforcement detailing design optimization are all other possibilities. There is no doubt that pioneering approaches and improved optimization applications in the detailed design of RC structures can be characterized by bringing attention to the limitations in the existing literature for future research.

This work synthesizes and analyses the literature on RC structural comprehensive optimisation over the last few decades using qualitative as well as quantitative techniques. It then identifies creating optimization gets closer, local requirements, generic and geographic study trends, study theme groups, limitations, challenges, and future research possibilities. This paper focused on peer-reviewed journals. It may be possible to expand the primary summary to incorporate additional conference reports and proceedings in the future.

Declaration of competing interest

The writers make the categorical assertion that they do not have any known conflicting financial interests or personal contacts with third parties that may give the impression that they were seeking to influence the work that is documented in this paper. The authors note that there is a possibility that this could give the impression that the authors were attempting to influence the work that is detailed in this article. The authors further state that they do not have any known interactions with any third parties that could have given the appearance that they were attempting to influence the work in any way, and they deny having any such contacts in the past.

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