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ACTION RESEARCH AS A PROACTIVE APPROACH FOR WASTE REDUCTION IN STRUCTURAL DESIGN PHASE OF CONSTRUCTION PROCESS

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ABSTRACT

Purpose: Research in construction engineering and management requires practical research approaches. However, the literature indicates that limited attention is focused on this issue and the methods used by most researchers are mainly quantitative surveys or case studies. In order to bridge this gap, this paper investigates how a proactive approach such as action research (AR) can be effectively adopted as waste identification and reduction in the structural design phase of the construction process. In other words, the paper explores the application procedures of AR as a data collection approach in South African consulting engineering firms.

Design/methodology/approach: This was achieved by conducting action research in five selected consulting engineering firms located in Bloemfontein, South Africa, in 2016. The firms that were selected were those that have engineers with extensive experience in the structural design process (SDP), and are affiliated with Consulting Engineers South Africa. In the AR study, waste that is significant with the structural design process (SDP) in South African construction were investigated. The causes of the waste, their frequency of occurrence in different projects and the strategies that can be adopted to overcome the waste were also investigated.

Findings: The findings in the exploratory study indicate that AR is a reliable, structured, and rigorous research approach that can be adapted to identify and reduce waste such as waiting time, design error, over-processing, excessive vigilance, overproduction, and correction/rework in the structural design phase of the construction process.

Practical Implications: The study shows that AR is a suitable approach that can effectively improve collaboration between researchers and industry practitioners for efficient projects delivery.

Originality/value: This paper satisfies all the tenets of originality as it has not been previously published and all the information obtained from other studies have been dully referenced.

Keywords: Approach; construction; design; proactive; process; waste

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1. INTRODUCTION

Construction engineering and management (CEM), by epistemology and axiology, is a "proactive" field as each construction project is an intervention into what exists and thus creates new reality (Azhar et al., 2010). Hence, CEM in its present form, does not prioritize abstraction and extraction of conceptual knowledge, and can be problematic to adequately understand through quantitative survey and case study methods (Benbasat and Zmud, 1999; Kelemen and Bansal, 2002). An approach that is clearly needed in CEM is a research method that can contribute to solution of practical problems and creation of new theoretical knowledge. A method that can be best described as action research (AR) (Azhar et al., 2010).

Action research (AR) is any practical research undertaken by those involved in the practice area (Buchy and Ahmed, 2007; Hughes, 2008). It is a process of enquiry by a researcher into the effectiveness of a particular organisation (Buchy and Ahmed, 2007; Hughes, 2008). According to Lewin (1948), the idea of AR started when practitioner researchers came across problems that needed immediate attention in their work. Lewin (1948) proposed the first AR methodological framework that was adopted by the practitioners to overcome the problems in their practice. Thus, Lewin (1948) explains AR as a cyclical process of four iterative stages of reflecting, planning, acting, and observing. Lewin (1948) methodological framework is unique as it produces highly reliable research results, which is grounded in practical action that aimed at solving a realistic problem situation (Elliot, 1994). The method also enables a researcher to effectively conduct a study without interfering with the phenomenon that is being investigated (Naoum, 2001).

Several researchers among which are Elliot (1994), Stringer and Genat (2004), Kemmis and McTaggart (2007), Buchy and Ahmed (2007), Mill (2011), McNiff and Whitehead (2011) have adopted Lewin (1948) AR methodological framework to identify and reduce problems in diverse researches. However, findings in literature show that AR is mainly on areas such as information systems, management, health care development and education studies (Cushman 2001; Hauck and Chen, 1998; Barker et al. 2004; Rezgui, 2007; Azharet al., 2010). The application of AR in engineering sector of construction is scarce in literature. Hence, this paper systematically examine how AR can be adopted to identify and reduce the problems (waste) confronted by structural engineers during SDP.

2. METHODOLOGY

The applicability of AR as a research approach in Bloemfontein consulting engineering firms was demonstrated through the adoption of the framework shown in Figure 1.

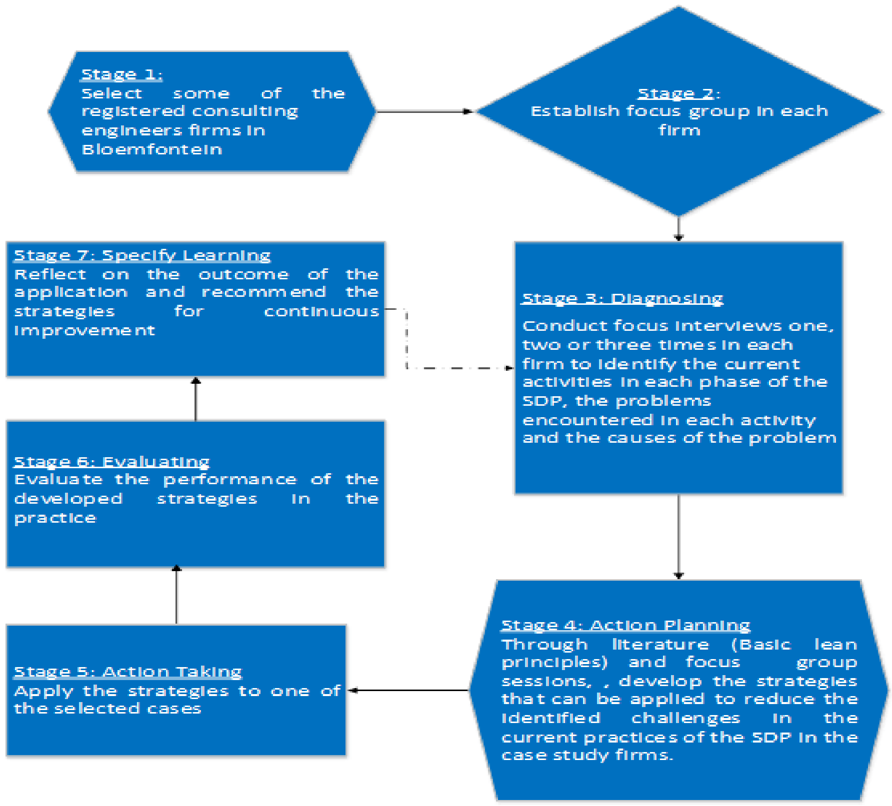

Figure 1: A methodological framework for conducting action research in Bloemfontein based consulting engineering firms (Adapted from Lewin, 1948; Mill, 2011; McNiff and Whitehead, 2011; Stringer, 2014)

As shown in Figure 1, after the establishment of focus groups, focus interviews were first conducted in all the firms so as to understand the current flow of activities in the inception design phase (IDP), the pre-design phase (PDP), and the detailed design phase (DDP) of the SDP (diagnosing phase). Thereafter, another round of interviews was conducted in each firm so as to enable the researchers and the participants in all the groups to propose for different strategies that can be adopted to eliminate the identified waste (action planning phase). For consistency, the focus interviews in each step of the study (diagnosing and action planning) were conducted thrice in each firm. Each focus interview in all the firms was between 60 to 80 minutes in duration. All the focus interviews discussions in each firm were recorded and transcribed. After transcription, the resultant information was analysed using content analysis method (Krippendorff, 2012). The resulting information from the interpreted data (themes) were validated using follow-up interviews, which were conducted by the researchers with the head (the chief engineer) of each group of respondents in all the studied firms.

The next phase of the study as indicates in the proposed methodological framework is the implementation stage. Here, the researchers, and the participants created a change in the activities of the firms by implementing the suggested strategies to the organisation practices. This was achieved by selecting one of the case study firms that had an ongoing project at hand as at the time of this study. The project is located in the region of Johannesburg, South Africa. Hence, the suggested strategies by the participants of the study and the researchers were implemented in the project right from the IDP to the structural design aspect of the construction phase (CP). As a collaborative effort, the structural engineers in other firms were also involved in the activities specifically at the design stage of the project.

After the implementation stage (stage 5), the researchers and the group members in the firm selected evaluated the changes that were created on the performance of the firm (stage 6), which was based on the executed project. In the evaluation phase, the researchers and the group members in the case firm determined whether the theoretical effects of the adopted strategies were realized or not and whether these effects reduced or completely eliminated the non-value adding activities (NVAA) in the SDP. These were achieved by summoning the group members together at the end of the main activities (structural design related activities) in the executed project, and find out from the group if the quality of the structural activities in the design and the construction phases in the newly executed project has been substantially improved through minimal mistakes or errors. The researchers also found out from the group members if the lead time (LT) formerly experienced during SDP by the team has been significantly reduced, and if the requests for information (RFIs) from the contracting party was also reduced during the structural design related activities in the CP of the new project.

3. Results and Discussion

3.1. Waste in the inception design phase of the structural design process

From the AR conducted in this study, Table 1 provides the summary of the various forms of waste and their causes in the inception design phase (IDP) of SDP. In the diagnosing phase of the AR exercise, all the respondents in all the firms agreed that the general categories of waste indicated in the table occur virtually in every construction project, with the exception of the waste categories of “ineffective site workflow” and “waiting for the site report”, which occur only occasionally. Some of the respondents did not agree that excessive soil test in the IDP is one of the design problems that needs to be addressed, or that requires action by management. The respondents argued that it is mandatory for designers to know the exact bearing capacity of soil in the proposed site, and, as such, they asserted that the professional tasked with this responsibility is obligated to take as many samples as possible during site visits, so as to arrive at a standard or acceptable result that is not compromised.

Table 1: Waste in the inception phase of the structural design process

Waste	Cause
Waiting for fund release from the clients before the start of work	Waiting for fund release before the start of structural work often results in wasted time in most of the studied firms, due to slow decision-making by the client.
Waiting for the start of structural work	This occurs due to late release of project funds by the client.
Ineffective site workflow	Ineffective site workflow or difficulties in accessing the site freely by the various construction actors during the site topographical survey, due to gaps in the topographical survey. Difficulties such as sloping, rocky, valley or high-hill surfaces result in ineffective workflow during this activity.

Several soil tests/site visits	The site soil test may have to be repeated two or three times before a satisfactory result is obtained, particularly when the proposed site has unstable soil. In the ideal situation, the soil test is carried out once, in an environment where there are existing structures that are similar to the proposed one.
Waiting to establish the scope of the work	These are caused by poor architectural briefing and too many changes made to the architectural drawings.
Waiting to implement contract agreement between the client and the designers	These occur mainly due to delays in understanding the scope of the work, due to changes made by the client to the architectural drawings.
Poor site report	This occurs when the information supplied by the geotechnical engineer conflicts with the existing knowledge of the structural design team (SDT).
Waiting for the site report	Site report writing wastes time, as the study shows that to write a good site report after site visitations takes approximately seven to eight weeks in some of the studied firms, due to laxness on the part of the geotechnical engineer (a poor site report). Waiting for the site report also occurs when the proposed site is in a remote location, where the necessary facilities for conducting the soil tests cannot be easily accessed.
Waiting for the compilation of inception design documents	These occur mainly due to lateness in completion of inception work, as a result of problems encountered in the process by the SDT.

3.2. Waste in the pre design phase

The pre design phase (PDP) is the second stage in the SDP, and its main objectives, according to the responses from the AR conducted, are to finalise the project concept, and to clearly lay out the procedures needed by the designers in order to complete the next phase of work. This implies that in the PDP, the SDT thoroughly studies the architectural plan and draws attention to the general layout and the preliminary sizing and stability of the proposed structural elements. Table 2 provides a summary of the types of waste in the PDP of a project. It is worth noting that all the respondents agreed that ambiguities in the architectural drawings are the main challenges at this stage of the work, as they are responsible for most of the problems encountered by the SDT. One of these ambiguities is specification for a large floor size.

Table 2: Waste in the pre design phase of the structural design process

Waste	Cause
Ambiguities in the architectural drawings	Ambiguities, such as wrong specifications of materials, slab thicknesses/sizes, and column sizes, due to a lack of communication between the architect and the SDT during the architectural process.

Disagreements between the architect and the SDT	Disagreements arise between the SDT and the architect in attempts to clarify information on aspects such as the number and the size of columns required for the proposed structure. Disagreements occur due to inadequate structural knowledge by the architect.
Excessive meetings between the client, the architect, and the SDT	Excessive meetings occur before the architect and the SDT reach consensus on issues regarding the architectural work.
Unnecessary waiting time due to design modifications	Unnecessary waiting time occurs during structural work, where the architect needs to effect changes to the architectural drawings, due to comments made by the SDT, or changes in client requirements
Several, lengthy, and repeated structural computations	This is due to lack of suitability of the existing technology; every structural work is unique in nature. Computations used for structural elements on previous projects cannot be used for structural elements on a new project
Wrong computations	These occur due to mistakes (human error) made by the SDT during the computation of structural elements. A typical example is the computation of sizes and permissible bending moments for each structural element. The procedures involved in performing these computations are routine in nature, and are sometimes boring, and can thus lead to human error, that is, mistakes. Wrong computations may also occur when the SDT misinterprets the building codes, or does not adhere to them strictly
Several printings of paperwork	This occurs due to human errors/mistakes made by the SDT during the structural work. It also occurs due to complexity in the architectural drawings
Excessive supervision of work by the chief engineer	This is caused by the stipulation of procedures in the consulting firms; the senior engineer is expected to cross-check every aspect of work carried out by the junior engineer/designer before moving on to the next phase of work
Waiting to establish preliminary design documents	This occurs mainly due to lateness in completion of the pre design work, as a result of problems experienced in the process by the SDT

3.3. Waste in the detailed design phase

With regard to the detailed design phase (DDP), it was discovered that this phase involves detailed consideration, determination and selection of the most suitable alternative solution in terms of the proportions, dimensions, and connections of structural elements defined in the pre design phase, in order to create the complete, perfect, and final structural drawings/specifications for the proposed project. Table 3 provides a summary of the different types of waste in the DDP of projects. Inability to complete tasks as earlier scheduled constitute the main problems in this phase of construction process.

Table 3: Waste in the detailed design phase of the structural design process

Waste/problem	**Cause**

Design corrections	Design corrections occur due to mistakes made by the SDT in critical areas during production of the structural drawings
Redesign	Redesign occurs when a structural element that is wrongly computed in the predesign phase is detected in the detailed design phase of the work
Unnecessary printings of draft work	Draft drawings at every stage of work are submitted to the chief engineer for necessary corrections and contributions before proceeding to the next stage
Inability to complete work as earlier scheduled	This is an inability of the SDT to complete work in accordance with the prepared work programme. The SDT has “no work timetable” due to the many contributions, corrections, and adjustments in the course of the work
Waiting for the approval of final drawings	Design work is being carried out by the junior engineer in the consulting firm, which will be submitted to the senior engineer, and thereafter to the project director of the firm or the chief engineer for corrections. This wastes time, as the chief engineer/project director has to thoroughly crosscheck every section of the work before final approval
Waiting to establish detailed design documents	This is due to all the problems experienced in this phase of the work by the SDT
Several copies of final work	Several copies of the final work are made, as recommended by the studied firms. All the construction actors must be given copies of the final work for documentation purposes.

3.4. Waste in the construction phase of projects

Table 4 provides a summary of the various types of waste in the construction phase of a project. According to some of the respondents in the AR study, excessive RFIs constitute the main problem in this phase, and RFIs may occur as many times as possible, particularly in a large project, such as the construction of a commercial or non-residential (multi-storey) building or an industrial building.

Table 4: Waste in the construction phase of construction projects

Waste/problem	Cause
Excessive RFIs	The construction contractors excessively request the presence of a member of the SDT on site for clarifications of information in the design drawings. This is due to lack of involvement by the construction contractor at the design stage of the structural work
Excessive waiting time during structural reinforcement	Excessive waiting time occurs during structural reinforcement. This is due to the complexity of the structural drawings. The construction contractors find it difficult to interpret some aspects of the structural drawings on site. A typical example is the top reinforcement of the foundation and stairs

Variation/changed orders	Changes in client requirements and changed orders occur on site due to sudden changes made by the client regarding the proposed structure, or unforeseen problems, such as foundation problems.
Redesign	Redesign becomes necessary on site when the materials specified are not available
Wrong fabrication of formwork, rebar cages, and reinforcing steel	This is due to improper or inadequate supervision of work by the construction contractors, or misinterpretation of the structural drawings. It may also be due to the complexity of the structural drawings
Excessive writing of site instructions	This occurs when there are several mistakes on site, particularly with regard to formwork, rebar cages, and reinforcing steel fabrications
Ineffective communication flow between the SDT and the construction contractor	This is due to lack of involvement of the construction contractor at the design stage of structural work. Human error is also a factor, that is, failure to understand the problem
Inadequate spacing of structural reinforcing materials	This occurs on site due to poor or inappropriate supervision of work by the construction contractor. It can also occur due to misinterpretation of the structural drawings
Excessive supervision of work	This is due to the need for the construction contractor to comply with the necessary regulatory authorities, that is, there must be supervision in every phase of a new task
Excessive cutting/fabrication of structural reinforcing materials	This is due to misinterpretation of the structural drawings by the construction contractor, or poor supervision of work.

3.5. Average frequency of occurrence of SDP waste in projects

Based on the opinions of the respondents in the QMAR conducted, Figure 2 concise the frequency of occurrence of SDP waste in different projects. In the figure, project 1 represents construction of a simple residential building, while projects 2 and 3 represent construction of non-residential (commercial) and industrial buildings.

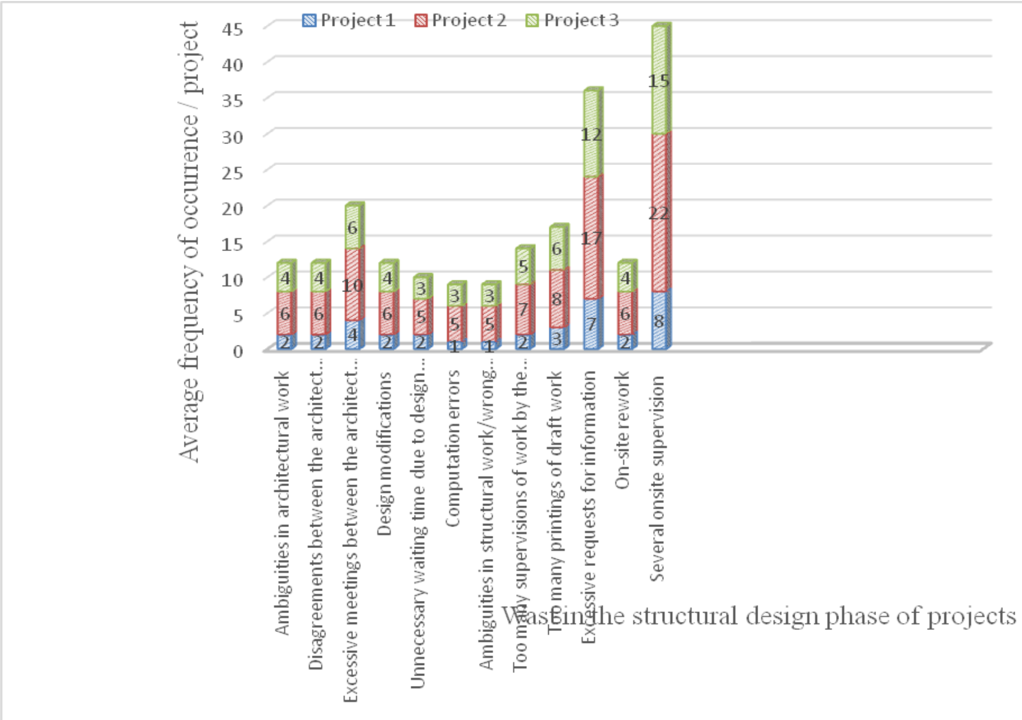

Figure 2: Frequency of occurrence of waste in three different construction projects

3.6. The categories of waste in the structural design process

Based on literature, the identified types of waste in SDP during the AR study can be grouped into nine categories, namely waiting time, over-processing, motion, excessive vigilance, overproduction, rework/correction, clarification, design error and work interruption as shown in Tables 5,6, 7 and 8.

Table 5: The categories of waste in the inception design phase

Categories	Waste
Waiting time	Waiting for fund release from the clients; waiting for the start of structural work; waiting for the site report; waiting to establish the scope of the work; waiting to execute contract agreement between the clients and the designers, and waiting for the compilation of inception design documents
Over-processing	Several soil tests, and several site visits
Motion	Ineffective site workflow

Table 6: The categories of waste in the pre design phase

Categories	Waste
Design error	Ambiguities in architectural work, and wrong computation
Overproduction	Several printings of paperwork
Over-processing	Excessive meetings between the client, the architect and the SDT

Motion	Several, lengthy, and repeated structural computations
Excessive vigilance	Several supervision of work by the chief engineer
Waiting time	Unnecessary waiting time due to design modifications, and waiting to establish preliminary design documents
Clarification	Disagreements between the architect and the SDT

Table 7: The categories of waste in the detailed design phase

Categories	Waste
Overproduction	Unnecessary printing of draft work, and several copies of final work
Corrections/rework	Design corrections, and redesign
Waiting time	Waiting for the approval of final work, and waiting to establish detailed design documents
Work interruption	Inability to complete work as earlier scheduled

Table 8: The categories of waste in the construction phase

Categories	Waste
Corrections/rework	Variation/changed orders; wrong fabrication of formwork; rebar cages/reinforcing steel; redesign, and inadequate spacing of structural reinforcing materials
Over-processing	Excessive requests for information, and excessive cutting/fabrication of structural reinforcing materials
Waiting time	Excessive waiting time during structural reinforcement, and ineffective communication flow between the SDT/the construction contractor
Excessive vigilance	Several on-site supervision

3.7. Strategies that can be adopted to reduce the identified waste

Several strategies that can be adopted to reduce the identified waste in the SDP were proposed by the participants in the AR study. These are concise in Tables 9, 10, 11 and 12.

Table 9: Strategies for waste reduction in the inception design phase of the structural design process

Waste	Strategies
Several meetings especially in the project initiation phase	Adoption of phone calls and internet enabled communication (IC) during the SDP

Lateness in the start of the structural design activities due to delay in the release of project fund from the client	Appropriate communication and regular meetings with the client
	Long-time loan from the various available funding agencies
	Commencement of every structural project from high level discussion before the involvement of the SDT
	All clients need to be realistic right from on-set
Gaps in the topographical survey of the proposed site	Timely conduction of the site topographical survey through the service of experienced land surveyors
Several soil tests	Assumptions of certain design variables based on the geotechnical information of the existing buildings in the proposed site
Waiting for/poor site reports	Early investigation of the various soil tests and land topographical survey by the various professionals
	Minimize assumptions during the geotechnical investigation of the proposed site
	The use of an experienced designer that understand the information required by the geotechnical engineers for the necessary soil test.

Table 10: Strategies for waste reduction in the pre design phase of the structural design process

Waste	Strategies
Ambiguities in the architectural designs	Adoption of quality assurance (QA) strategy in every architectural design firm
	Involvement of the structural designers in architectural process
	Adequate and continuous communication between the SDT and the architects during the architectural process
Excessive meetings and disagreements between the architect and the SDT	Involvement of the SDT in the architectural process
	Adoption of meeting agenda and schedule of work or roster in every project

Modifications of architectural drawings and unnecessary waiting time due to the design modifications

Involvement of the SDT in the architectural process

Several repeated structural computations	The use of programmed excel spread sheet, adoption of some developed generic assumptions or a design software such as REVIT structure for structural computation
Computations errors/wrong computations	Carefulness in the adoption of certain design assumptions and some structural software
	Proper adoption of QA procedures
	Complete engagement of a long time and experienced senior engineer in the necessary structural computations
Several printings of paperwork	Adoption of EC by the various project actors
	Avoidance of all form of complexities in the architectural and the structural drawings
Excessive supervisions of work by the chief engineer	More engagement of a senior designer in the calculation aspect of the structural work

Table 11: Strategies for waste reduction in the detailed design phase of the structural design process

Waste	Strategies
Design corrections	Adequate involvement of experienced designers such as senior engineers in every aspect of the SDP

Redesign	Implementation of DVSP or GP in the SDP
	Penalizing DVSP defaulters
	Avoidance of vague assumptions and design variations in the SDP
	Adequate involvement of the client in every phase of the SDP or proper communication between the client and the SDT in every phase of the SDP
	Adequate engagement of an experienced designer such as senior engineer in the computation aspect of the structural design
Delay in selection of the suitable structural elements computed in PDP, delay to incorporate the comments made in the PDP into work and inability to complete work as earlier scheduled	Proper planning and communication between the senior and the junior engineers and the client
	Total commitment among the various design actors and the client
	Appropriate communication for additional resources such as man powers when the need arises

Table 12: Strategies for waste reduction in the construction phase of projects

Wastes	Strategies
Excessive RFIs, Construction reworks, excessive writing of site instructions and excessive waiting time during the structural reinforcement	Production of drawings that is free of mistakes/errors and unambiguous to understand and interpret on the site
	Involvement of construction contractors in the design process
	Full time engagement of a structural engineer at the construction phase of projects
	Engagement of a structural engineer for reasonable hours for clarification of the technical aspect of construction drawings before the start of site activities
Variations/change orders and redesign	All forms of project variability are to be avoided during site activities
	Project actors are to defer the execution of the technical aspects of work that are liable to changes during construction activities until final decision has been taken by all project actors
Wrong fabrication of formwork, rebar cage and reinforcing steel and excessive cutting or fabrication of structural reinforcing materials.	Engagement of the services of experienced contractors and subcontractors
	Full time engagement of a structural engineer at the construction phase of projects
Ineffective communication flow between the SDT and the construction contractor	Production of more sections or details of some technical aspects of construction drawings for simplicity of every design information
	Engagement of the service of an experienced contractor

4. Study Implications

The study offers guiding information on how a method such as AR can be adopted to identify and reduce waste in the SDP. Hence, the proposed methodological framework allows structural engineers to identify gaps in their implementation efforts, focus attention on areas for improvements, and assess the benefits of AR in the design and the construction phases of projects. In words, the study provides structural designers in South African consulting engineering firms a method that can be adopted to identify and reduce waste such as overproduction, over-processing, motion, waiting time, excessive vigilance, correction/rework, and design error during SDP.

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5. Conclusion and Recommendations

The main goal of this paper was to provide guidelines for conducting AR in consulting engineering firms. The methodological framework presented in Figure 2 was followed in the various case study firms described in this paper. Hence, AR can be conducted in consulting engineering firms to effectively improve collaboration between researchers, and industry practitioners for efficient projects delivery. AR is not without its problems for researchers. The literature reveals that the cyclical process in AR study needs to be repeated several times for continuous improvement. This implies that the proposed methodological framework (Figure 2) needed to be repeated perhaps two or three times in different projects before being drawn to a conclusion. However, it should be noted that construction process is a project that may take 10 to 14 months in duration (from the inception stage to completion). This made the researchers reach the conclusion of the AR study after the first cycle. With the single cycle conducted, the purpose of this study was observed to be met as the researchers ensured that the action-planning and action-taking phases in the AR plan were repeated until the saturation states were reached (three times). With these saturation states, it can be contended that if the AR process is repeated the second time, there might be no additional information or new knowledge or findings. Therefore, for effective AR study in the engineering aspect of construction, attention should be focused mainly on action-planning and action-taking phases.

Further, based on the findings of QMAR conducted, it can be concluded that waste occurs in every phase of the SDP, although the frequency of their occurrence differ from one project to another. Typical examples of these types of waste are waiting time, design error, over-processing, excessive vigilance, overproduction, and correction/rework. This paper also concludes that the discovered waste in the SDP can be reduced through the application of the strategies suggested in the action planning phase of the QMAR conducted (Table 9, 10,11 and 12 of this paper). Among these strategies is adequate involvement of the structural design team (SDT) in the architectural process (AP). This is in agreement with the views of Forbes and Ahmed (2011), Eastman et al. (2008) regarding the application of information and communication technology platforms for waste identification and reduction in the design and the construction phases of projects. Another notable strategy is to limit/discourage all forms of variability by the various actors the moment a project get to the DDP and the CP of projects. This discovery is also consistent with the findings of Mossman (2009) and Nagapan et al. (2012) regarding some of the waste elimination strategies in projects.

This study recommends the methodological framework presented in Figure 2 of this paper as a suitable outline for prospective researchers that intend to conduct AR in consulting engineering firms. Further studies should be conducted on the applicability of AR as waste identification and reduction in other aspects of construction process such as electrical/mechanical design process.

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