Journal of Construction in Developing Countries, 19(1), 127–140, 2014

Design Phase Constructability Improvement Strategies for Highway Projects in Uganda

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Abstract: There is great concern regarding the escalation of project costs and delayed completion of road work in Uganda. This has been partly associated with a lack of constructability. Studies have demonstrated that improved constructability leads to significant improvements in project cost savings and reduced completion times. The main aim of this study was to establish design phase constructability improvement strategies for highway projects in Uganda. A pragmatic approach of both qualitative and quantitative research methods was used for this study. Concepts of constructability were identified and rated. Using factor analysis, major design phase constructability improvement recommendations were identified. These factors include conducting formal constructability reviews; ensuring adequate materials design, communication, coordination and scheduling; analysing jobsite accessibility and storage requirements; engaging experienced personnel and adopting Computer Aided Design (CAD); ensuring thorough site investigation and clear design information; and developing designs that are sensitive to safety and weather conditions. The primary recommendation is to include constructability reviews to form part of the formal design process, using a separate team of construction experts (consultants) that are distinct from the design consultant before the construction stage of the project.

Keywords: Constructability, Design phase, Strategies, Highways, Developing countries

INTRODUCTION

There has been increasing concern across the world among transportation officials, contractors and design professionals that the plans and specifications do not always allow highway projects to be constructed as designed (American Association of State Highways and Transportation Officials [AASHTO], 2000). When this occurs, projects are delayed, project costs increase and, frequently, costly construction claims develop. Of equal concern are the delays and disruptions to motorists and the impact of delayed transportation projects on the economy (AASHTO, 2000). In Uganda, several road projects have experienced delays and cost overruns because of the lack of constructability as manifested by design disputes among the clients, contractors and consultants. According to the Public Accounts Committee (PAC) Report (2010), the 21-km-long Kampala–Northern bypass road was delayed twice because of design disputes and both disputes were settled by awarding costly claims to the contractor. The Auditor General's Report (2010) on the roads reported that some designs for road works were found to be improper, with excessive or inadequate designs and often lacked the necessary drawings. Furthermore, the same report noted that most designs did not take into account the most appropriate and economical solutions.

According to Anderson, Fisher and Rahman (1999), constructability is seen as one of the best solutions to problems in which there is demonstrated potential to minimise the number and magnitude of changes, disputes, cost overruns and

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delays during construction. According to Bambang (2004), the concept of constructability emerged in the late 1970s from research on how improvements could be achieved to increase cost efficiency and quality in the construction industry. Studies in the USA, UK and later in Australia have demonstrated that improved constructability leads to significant savings in both the cost and time required for completing construction projects (Bambang, 2004). According to Wright and Obrien-Kreitzberg (1994), early constructability efforts result in a significant payback to the project, with cost reductions of between 6% and 23%, benefit/cost ratios of up to 10:1 and large schedule reductions. However, as with most construction projects, implementing highway constructability improvement can be very challenging because it is important to consider each country's unique construction industry. Researchers in the developed countries have identified this shortcoming and suggested various approaches to mitigate it (Bambang, 2004). However, in developing countries, there is a dearth of knowledge concerning efforts to improve constructability. This could be partly because constructability has not been understood by the stakeholders. This study's overall objective was to establish design phase constructability improvement strategies for highway projects in Uganda.

LITERATURE REVIEW

According to the Construction Industry Institute (CII) (1986), constructability is defined as "the optimum use of construction knowledge and experience in planning, designing, procurement and field operations to achieve the overall project objective", while the Construction Industry Institute Australia (CIIA) (1996) defined constructability as "the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goals and building performance at an optimal level". These definitions highlight the blending of construction knowledge into the project delivery process, encompassing all project stages and paying attention to environmental constraints to achieve desired project goals at an optimal level. The aim is to focus on design phase constructability concepts. Constructability was taken as an approach that integrates construction knowledge and experience in the project delivery process, especially at the design stage to minimize the cost and time required to complete the project. To achieve this, experienced construction personnel are involved with the project from the earliest stages – especially at the design stage.

Several studies on constructability have been conducted since the late 1970s. From these studies, several concepts have been identified for the various project stages. For purposes of this research, focus has been on design phase constructability concepts. According to Anderson, Fisher and Rahman (1999), it is generally agreed that the maximum benefits of constructability occur when constructability is initiated at the inception of a project. It is during the early project phases that key decisions regarding project scope are made and that scope changes are implemented with minimum difficulty. These decisions, if made in a timely manner, can result in maximum savings to the project.

The Construction Industry Research and Information Association (CIRIA, 1983) conducted one of the earliest studies on design phase constructability concepts in the UK. According to its study, CIRIA identified seven concepts for implementation during the design phase. The following concepts were included: conduct a thorough investigation and design; plan for essential site production requirements; plan for a practical sequence of operations and early enclosure; plan for simplicity of assembly and logical trade sequences; detail for maximum repetition and standardisation; detail for achievable tolerances; and specify robust and suitable materials. Research by Adam (1989) identified the following early phase constructability concepts: Investigate thoroughly; Consider access at the design stage; consider storage at the design stage; design for minimum time below ground; design for early enclosure; use suitable materials; design for the skills available; design for simple assembly; plan for maximum repetition and/or standardisation; maximise the use of a plant; allow for sensible tolerances; allow for a practical sequence of operations; avoid return visits by trades; plan to avoid change to work by subsequent operations; design for safe construction; and communicate clearly.

The other basic study was written by Boyce (1991), in which he offered 10 concepts for improving constructability during the design phase only. He called them "The 10 Commandments of KISS Design": Keep it straight and simple; Keep its specification simple; Keep it shop standard; Keep its standards simple; Keep it standard size; Keep it same size; Keep it square and squatty; Keep it support simple; Keep it site suitable; and Keep its schedule sacred. From the study conducted by Rosli (2004), there are 18 concepts for the design phase: carry out thorough investigation of the site; design for minimum time below ground; design for simple assembly; encourage standardisation/repetition; design for preassembly and/or modularisation; analyse accessibility of the jobsite; employ any visualisation tools to avoid physical interference; investigate any unsuspected, unrealistic or incompatible tolerances; investigate the practical sequence of construction; design to avoid return visit by trade; plan to avoid damage to work by subsequent operations; consider storage requirements at the jobsite; investigate the impacts of design on safety during construction; design for the skills and resources available; consider suitability of designed materials; provide detailed and clear design information; consider adverse weather effects in selecting materials or construction methods; and design for early enclosure.

The constructability concepts that were identified to be applicable to the design phase are summarised in Table 1.

METHODS

This research was carried out in two stages. Stage one involved a wide literature review to identify design phase constructability concepts applicable in highway projects. Stage two involved data collection to establish the level of importance and application of the identified design phase constructability concepts. Then, the level of importance and the level of application of the identified design phase constructability concepts on highway projects in Uganda were factored and analysed.

The research was conducted using a questionnaire survey. The questionnaire was compiled based on the concepts identified during the literature review and refined during the pilot study. The piloting was to capture the concepts that were not identified during the literature review and to improve the wording and increase the reliability of the questions. The questions were of closed type because it is easier and faster to analyse the information collected. The respondents were requested to give the level of importance of each concept with the scale ranging from "very important", "important", "moderate", "little importance" to "not important" rated 5, 4, 3, 2, 1, respectively, a 5-point Likert scale. For each of these 22 constructability principles, the survey respondents were also asked to rate the perceived or known degree of application of each of the concepts based on their experience. They had to choose from "always applied", "often applied", "sometimes applied", "rarely applied" and "never applied" (rated 5, 4, 3, 2, 1 respectively).

Table 1. Summary of Design Phase Constructability Concepts

Design Phase Constructability Concepts	**References**
Carry out thorough investigation of the site	CIRIA, 1983
Provide detailed and clear design information, including plans and specifications	Nima et al., 2002; Rosli, 2004
Carry out formal and adequate early review of the designs	Rosli, 2004; Siti, 2005
Plan for adequate coordination of designs, plans and specifications	Adam, 1989; Anderson, Fisher and Rahman, 1999
Design for effective traffic control	Adam, 1989; Anderson, Fisher and Rahman, 1999
Analyse accessibility of the jobsite	Adam, 1989
Investigate the practical construction phasing and scheduling	Boyce, 1991; Rosli, 2004
Investigate any unsuspected, unrealistic or incompatible tolerances	CIRIA, 1983; Adam, 1989; Siti, 2005
Consider suitability of designed materials	Boyce, 1991; Rosli, 2004
Design for the skills and resources available	Adam, 1989; Rosli, 2004
Employ computer software design and visualization tools	Newton, 1998; Rosli, 2004
Consider storage requirements at the jobsite	CIRIA, 1983; Adam, 1989; Rosli, 2004
Investigate the impacts of design on safety during construction	Adam, 1989; Rosli, 2004; Siti, 2005
Consider adverse weather effects in selecting materials or construction methods	Nima et al., 2002; Rosli, 2004
Design for simple assembly	Boyce, 1991; Rosli, 2004
Design for preassembly and/or modularisation	O'Connor, Larimore and Tucker, 1986; Rosli, 2004

(*continued on next page*)

Table 1: (*continued*)

Design Phase Constructability Concepts	**References**
Plan to avoid damage to work by subsequent operations	Adam, 1989; Rosli, 2004
Engage design personnel that have practical experience and knowledge of highway construction	Anderson, Fisher and Rahman, 1999
Encourage standardisation/repetition	CIRIA, 1983; Rosli, 2004
Design for minimum time below ground	Adam, 1989; Rosli, 2004
Design to avoid return visit by trade	Adam, 1989; Rosli, 2004
Design for early enclosure	CIRIA, 1983; Adam, 1989

This study targeted tarmac road projects completed within the period of 1 January 2004 and 31 December 2009. This is because according to the Public Procurement and Disposal of Public Assets (PPDA) Act 40 (1), the Procuring and Disposing Entity (PDE) must retain its procuring and disposal records for up to seven years. This period was selected to analyse projects that had been completed after the PPDA Act (2003) went into effect, while keeping within the seven-year period. The respondents were the professionals, including consultants, engineers, project managers and architects involved in their design and construction. A list of 20 projects fitting the scope of this study was obtained from the Uganda National Roads Authority (UNRA) (2009) and from this list, 10 projects were selected and 80 questionnaires were sent randomly to professionals working for the corresponding private and public institutions involved.

RESULTS AND DISCUSSIONS

Respondents

Data analysis was performed for 60 questionnaires (out of the 80 respondents) that were duly completed and returned to the researcher, equating to a response rate of 75%. As Figure 1 shows, 58.3% of the respondents work in consultancy firms, 26.7% work with highway contractors and 15.0% work with the UNRA. The distribution of respondents is representative because the biggest players at the design stage are the consultancy firms. Contractors are the next key players, involved in the project implementation and UNRA's role is profound during the conceptual and design stage.

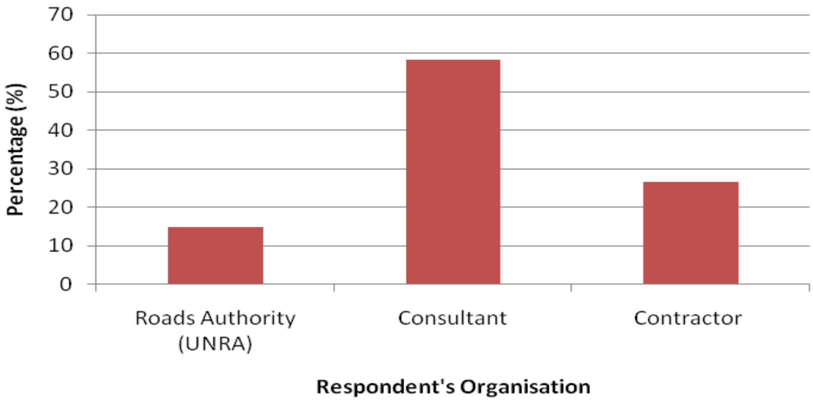

Figure 1. Distribution of Respondents by Type of Organisation

Of the respondents, 70% are engineering professionals with a Bachelor of Science in Engineering or equivalent qualifications, 25% are engineers with advanced degrees and the other 5% have higher diplomas in Civil Engineering or the equivalent. This implies that most of the respondents are professionals that are knowledgeable about the subject matter. Figure 2 shows the position held by the respondent in the organization. As is evident, all the categories listed have key roles in the design process.

Figure 2. Distribution of Respondents by Role

Five per cent of the respondents had zero to five years of experience working on highway projects, 60% of the respondents had six to 10 years of experience, while 30% of the respondents had 11–15 years of experience. Five per cent of the respondents had more than 15 years of experience, as shown in Figure 3.

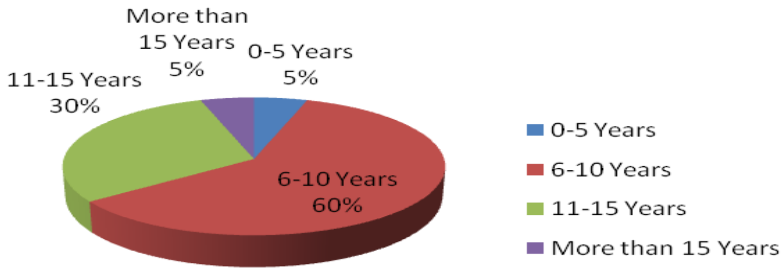

Figure 3. Distribution of Respondents by Experience

Ninety-five per cent of the respondents knew about constructability before this survey, as defined in the questionnaire. The other 5% of the respondents had never heard this term before. It is indicative that the majority of the respondents were aware of constructability prior to the survey, hence making the survey much more meaningful because these respondents knew about the subject of the study.

Cronbach's Alpha Reliability Testing

The Cronbach's Alpha Reliability analysis of the questionnaire was performed to determine whether the questionnaire was capable of yielding similar scores if the respondents used it twice. The alpha values obtained were 0.873 and 0.903 for level of importance and level of application, respectively, for all of the items. According to Reynold and Santos (1999), an alpha greater than 0.7 implies the instrument is acceptable. Therefore, according to the above results, the instrument was found to be of high reliability and thus acceptable.

Average Index Analysis for the Degree of Importance and Application

Average index analysis was used in the study to show the degree of importance and application of the various constructability concepts in the design phase of highway projects. It was computed using the following formula adopted from Al-Khalil and Al-Ghafly (1999: 649)

$$A.I = \sum (a_i f_i / N)$$

where
a = constant expressing the weight assigned to each responses,
f_i = frequency of each response and
N = total number of responses.

Table 3 shows the overall results for the average index analysis values for the identified constructability concepts during the design phase degree for the level of importance and the level of application. The concept with the highest average index value was ranked 1st and the concept with the lowest value was ranked last. The concept serial numbers are according to those given in Table 1.

Factor Analysis

Factor analysis was conducted on the degree of importance and the level of application of the 22 design phase constructability concepts. During the factor analysis, the principle component analysis was used to extract components whose Eigenvalues were over 1.000. According to Amin (2005), components whose Eigenvalues are less than 1 are no better than individual variables. Before carrying out the factor analysis, the Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy were used to determine whether factor analysis was possible.

Table 2. Indices for Importance and Application Ranks of Constructability Concepts

Concept No.	Average Index	Importance Rank	Average Index	Application Rank
C1	4.93	1	3.90	1
C2	4.90	2	3.87	2
C3	4.55	5	3.62	4
C4	4.45	6	3.55	5
C5	4.15	11	3.13	12
C6	4.17	10	3.27	8
C7	4.28	7	3.28	7
C8	3.98	14	2.80	16
C9	4.67	3	3.52	6
C10	4.22	9	2.93	14
C11	3.90	15	3.27	9
C12	3.57	16	2.93	15
C13	4.15	12	3.17	11
C14	4.27	8	3.08	13
C15	3.53	17	2.58	17
C16	3.15	18	2.52	18
C17	4.05	13	3.22	10
C18	4.62	4	3.73	3
C19	2.75	21	2.30	21
C20	2.92	20	2.42	19
C21	3.03	19	2.32	20
C22	2.75	22	2.17	22

Furthermore, according to Field (2005), a value of 0 indicates that the sum of partial correlations is large relative to the sum of correlations, indicating diffusion in the pattern of correlations (hence, factor analysis is likely to be inappropriate). A value close to 1 indicates that patterns of correlations are relatively compact; therefore, factor analysis should yield distinct and reliable factors. It also indicates that values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good, values between 0.8 and 0.9 are great and values above 0.9 are superb. These tests were carried out on the overall responses to the degree of importance and the level of application of the 22 design phase constructability concepts.

The KMO measure was found to be 0.712. The approximate Chi-square in the Bartlett's Test of Sphericity was 686.360 and the significance of the Bartlett's test was 0.000. Therefore, for these data, the KMO falls in the range of good; therefore, factor analysis was possible. Table 3 shows the Rotated Component Analysis for the level of importance and the level of application.

Table 3. Rotated Component Matrix for the Level of Importance and Application

	Level of Importance						**Level of Application**				
	Components						**Components**				
	2	3	4	5	6		1	2	3	4	5
C1				0.832		A1	0.665				
C2	0.446			0.768		A2	0.687				
C3						A3	0.750				
C4	0.816					A4	0.811				
C5	0.503				0.650	A5	0.759				
C6		0.666				A6	0.675				
C7	0.559					A7	0.650				
C8	0.851					A8	0.411	0.648			
C9	0.609					A9	0.843				
C10		0.478	0.511			A10	0.553	0.513			
C11		0.440	0.525			A11	0.735				
C12		0.606				A12	0.437	0.508	0.600		
C13					0.705	A13	0.591			0.558	
C14		0.434			0.661	A14	0.763				
C15		0.565				A15	0.508	0.505			
C16						A16	0.626				
C17			0.755			A17	0.612				
C18			0.788			A18	0.728				
C19						A19	0.472		0.428		
C20		0.756				A20	0.451	0.543			
C21				– 0.547		A21	0.520				0.512
C22						A22	0.548	0.490			

Notes:
1. Five components were extracted for level of importance
2. Five components extracted for application

Five components were extracted for level of importance and five factors were extracted for the level of application, as in Table 3. With these components, 69.9% of the total variances were accounted for by both importance and application.

DISCUSSION

Table 2 shows the results for the average index analysis values for the degree of importance and applicability of the various constructability concepts during the design phase. The overall average index is 3.95, which is "important", according to the adopted classification of the index scales in Table 4.

Table 4. Classification of Index Scales

Index scale	Importance Range	Application Range
1.0 ≤ Average Index < 1.5	Not important	Never applied
1.5 ≤ Average Index < 2.5	Little importance	Rarely applied
2.5 ≤ Average Index < 3.5	Moderate	Sometimes applied
3.5 ≤ Average Index < 4.5	Important	Often applied
4.5 ≤ Average Index < 5.0	Very important	Always applied

Hence, from the results obtained, it is indicative that overall, respondents consider all of the listed constructability concepts to be "important" during the design phase. The highest average index obtained is 4.93 for the concept "Carry Out Thorough Investigation of the Site", which is "very important" and the lowest is 2.75 for the concept "Design for Early Enclosure". Five concepts were rated as being "very important", 12 concepts were rated as being "important" and five concepts were rated as being "moderate". Hence, the results show that 17 out of the 22 concepts are rated as "very important" or "important" and only five concepts are rated as being "moderate".

Table 2 also shows results for the average index analysis for the degree of application of the various constructability concepts during the design phase. The overall average index is 3.07, which is "sometimes applied". Hence, the results indicate that overall, respondents consider all of the listed constructability concepts to be "sometimes applied" during the design phase. The highest average index obtained is 3.90 for the concept "Carry Out Thorough Investigation of the Site", which is "often applied" and the lowest is 2.17 for the concept "Design for Early Enclosure", which is "rarely applied". None of the concepts is rated as being "always applied". This suggests that none of these concepts is "always applied" according to the classification of the index scales in Table 4.

Six concepts were rated as being "often applied", 12 were rated as "sometimes applied" and four were rated as "rarely applied". With the overall average index of 3.07, which is rated as "sometimes applied", these results indicate that these concepts are judged as being "sometimes applied" during the design phase of highway projects. By comparison to the perception of importance, this is a lower rating. It is apparent that the respondents are of the view that the application of these concepts is not that high, but rather a low application on the projects they have participated in.

Five factors for the level of application were extracted in the factor analysis. These were identified as: ensure thorough site investigation and clear design information; develop designs that are sensitive to safety and weather conditions; assess the jobsite accessibility, storage requirements and encourage standardisation; engage experienced personnel and adopt CAD; and ensure adequate design of materials, communication, coordination and schedules.

Six factors for the level of importance were extracted in the factor analysis: carry out formal constructability reviews; ensure adequate design of materials, communication, coordination and schedules; analyse the jobsite accessibility and storage requirements; engage experienced personnel and adopt CAD, ensure thorough site investigation and clear design information; develop designs that are sensitive to safety and weather conditions.

Formal constructability reviews involving an independent and detailed analysis of all of the contract drawings and construction documents should be conducted before their release for construction. This review should ensure that the final design is simple to execute. The simplicity of design should encompass adoption of preassembly and modularisation where suitable instead of using in situ members, especially for works involving the application of concrete, such as bridges and fly-overs (Siti, 2005). This factor should also focus on the elimination of return visits by trade and encourage early enclosures and the standardisation and repetition of best practices in highway construction based on lessons learned.

The project management team should ensure that there is adequate communication throughout the entire project, with appropriate mechanisms for regular coordination of designs, plans and specifications. Joint reviews regarding the practical construction phasing and scheduling of the project should be carried out to monitor progress and avoid delayed completion. Similarly, compatibility of specifications and suitability of materials should be regularly reviewed by both the contractor and the designer to ensure suitability and to pre-empt the possibility of disputes. For highway projects, jobsite accessibility is more complex than for building construction sites. This includes the client ensuring that the proposed highway route is secure and available to the contractor prior to the commencement of construction. Such access also includes the prior design for required road diversions as well as the conclusion of all settlements requiring compensation of residents along the project route, including the road diversion areas (Nima et al., 2002).

Proper planning for material storage is also key in ensuring the reduction of multiple handling of materials and the protection from weather damage of materials or finished work (Rosli, 2004). Planning reduces damage through general carelessness and loss resulting from handling and stacking materials during delivery, storage and movement around the site. This factor is more pronounced for highway projects in congested urban areas.

Design personnel with practical construction experience should take the lead in the design process. These personnel should make use of CAD technologies to investigate the design suitability and carry out a value analysis before construction commences on site (Nima et al., 2002). Consequently, they should be able to foresee any potential problems with the design before actual construction starts. With the aid of such technological tools, the designers will be able to match the completed design with the skills and resources to execute it.

One of the major challenges has been commencement of highway construction before designs are complete (Alinaitwe, 2008). Site investigations should be thorough, complete and clearly presented. The findings of such investigations should be made available to the contractor before the tendering procedure and thus before the start of construction. These investigations should include ground conditions, underground hazards and other geotechnical data suitable for the proper execution of the project. Additionally, detailed and clear design information, including plans and specifications, should be prepared before the commencement of construction. This core activity must be budgeted for and sufficient time and resources should be permitted in the project budget to provide complete project information and reliable design information to the contractor.

Designs should be developed with consideration for construction site safety (Alinaitwe, Mwakali and Hansson, 2007). As part of the safety considerations, designers should ensure that the executed works involve a minimum risk of damage from subsequent operations. Also, considerations should include a practical plan for traffic control during construction. Assessment should be made of on-site characteristics and traffic patterns prior to the commencement of construction and a comprehensive traffic control plan should be developed. Designers also ought to consider the effects of adverse weather, such as heavy rains, on the entire construction process. Construction methods, schedules and materials should therefore be specified after a project-specific assessment. Therefore, the role of project managers cannot be over-emphasised on construction projects if constructability is to be achieved.

CONCLUSION AND RECOMMENDATIONS

This study investigated design phase constructability improvement strategies for highway projects in Uganda. Twenty-two design phase concepts were identified from the literature and used in the questionnaire to determine their level of importance and degree of application. It was found that whereas the degree of importance of the identified concepts was very high, with an overall average index of 3.95, the level of application of the identified concepts was low, with an overall average index of 3.07. From this study, therefore, it is apparent that whereas the respondents consider all the identified concepts to be important, they consider their level of application to be low. Factor analysis was used to determine the most important design phase constructability improvement factors for highway projects in Uganda. Five main design phase constructability improvement factors were identified: conduct formal constructability reviews; ensure adequate design of materials, communication, coordination and schedules; analyse the jobsite accessibility and storage requirements; engage experienced personnel and adopt CAD; ensure thorough site investigation and clear design information; and develop designs that are sensitive to safety and weather conditions. These factors, when applied, should serve as a basis for strategies to improve design phase constructability for highway projects in Uganda.

Constructability will achieve greater success when its improvement factors become a formal part of the way in which a construction project is conceived, organised and managed. For benefits to be guaranteed, therefore, the sector regulator should have a formal constructability review policy according to which these factors are applied. This policy should be actively pursued through a structured programme of measures designed to encourage constructability from day one of the project's conception.

Because highway projects in Uganda are primarily delivered using the traditional approach, a project management consultant should be retained separately from the design consultant, whose task should include constructability review as well as incorporation of construction inputs into the design from the beginning of the design process. These lessons learned should be maintained as guides, as they could ultimately lead to constructability improvement of subsequent highway projects in Uganda. Furthermore, there should be adequate communication between the project management consultants, the clients and the contractors for the project to benefit from the constructability reviews.

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