

INFLUENCE OF COLLABORATIVE RELATIONSHIPS ON THE PERFORMANCE OF DESIGN-CONSTRUCTION EFFICIENCY OF INDUSTRIALIZED CONSTRUCTION

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Supplemental file 1. Case studies

1.1. Apt. 16 (Case A)

Apartment number 16 (Apt 16) is one of the first series of prefabricated residential building projects in the city of Addis Ababa (see Figure 1). The project applied the IMS pre-stressed concrete structural system for the purpose of speedy construction in order to achieve a high rate of housing provision. Based on the delivery mode of the construction work the building has two clearly discrete phases of assembly. The first part is the foundation and structural parts assembly phase which took only six months for completion, whereas the second part took more than 7 years of over extended time due to not only the mode of the delivery system but also mainly it was because of the lack of finance, material availability, concurrent management

of the onsite construction, and political instability as well as regime change within the country.

Apt 16 was structured around several separate trade agreements on multiple integration levels of delivery which were largely organized by the main three stakeholders of the project (see Table 1). They are the product delivery company of the Ethiopian Prefabricated Building Parts Production Enterprise (EPBPPE), Building Design Enterprise – the company that took care of the design and supervision of the project and that of the government Agency for the Administration of Rental Houses – the owner of the project. Although EPBPPE had fully involved in the production and assembly of the foundation and the structural framework, however, the materials and components for infill and finishing parts of the construction works were delivered by the company named Awash Construction plc.



Figure 1. Apartment buildings located along the main Bole road

Table 1. List of stakeholders participated in the Apt 16 project

Organization	Participant category
Rental Housing Agency	Client
Building Design Enterprise	Supervisor
Building Design Enterprise	Designer
Awash construction	Contractor
Prefabricated Building Parts Production Enterprise (EPBPPE)	Manufacturer
Local workshops	Special subcontractor
Local suppliers	Supplier

1.2. Special housing (CMC) project in Addis Ababa (Case B)

The project is situated in an area of approximately 22 hectares and distributed among 56 buildings of varying architectural styles (see Figure 2). 500 apartment units for diplomats and higher government officials as well as various shops and service buildings were constructed. The Ministry of Urban Development and Housing, as the owner of the project, had selected the important actors who participated in a different role in the project (see Table 2). The construction work of the five hundred apartments was assigned to Cooperativa Muratorie Cementisti C.M.C of Ravenna (Italy). The design and supervision were commissioned to Foster Wheeler Italiana of Milan (Italy) with collaboration with Ethiopian Building and Transport Construction Design Authority as a contract management consultant.

As a (turnkey) contract, CMC is focused on the execution and construction phases or stages of a building project. Project design and design development are mostly limited to the technical engineering disciplines and are based on proposed layouts from Foster Wheeler Italiana of Milan (Italy). The modularization of the building process into its component elements is at the outset based on the company's conventional procedures. However, CMC has also worked with the building components developments and their manufacturing by establishing a production and development center. The components are developed to be applied to different types of housing modules and with a maximum integration capacity for ease of installation on-site as well as a further physical commoditization.

1.3. Yi Hui Tang project (Case C)

This project is a new type of building industrialization demonstration project having 2 floors with a total construction area of 350 m² (see Figure 3). The building was constructed and put into use within three months. The component classification design method contributes to the smoother collaboration among the stakeholders with a clear objective and better communication. The collaboration helps to achieve effective construction management and improve the quality and duration of project completion. The overall building is divided into two major categories, i.e., structural body groups and other component body groups. The structural body groups of the building were further divided into different categories such as basic structural body, the extended structural body, the basic enclosure body, and the

extended enclosure body. Each component body group was designed and developed separately on which it was suitable for professional manufacturers to collaborate from the initial stage of the design development.

The construction process was organized around a relatively large amount of individual trade contracts directly between the client, Changzhou Institute of Building Science, and different contractors. The project-specific splits of responsibilities were established during the design development stage (see Table 3). This form of procurement is called collaborative construction management and the individual contracts are called trade contract packages or simply: work packages. The work interfaces of the collaborative design were clearly divided to avoid problems in the relationship and connection between the components. This gives all the participants an enhanced control over the specific division into contracts.

The work packages behind the trade contracts of this project were parallel, as opposed to the traditional serial system. Within each work package, the trade contractor was responsible for the entire supply chain from design to manufacturing and assembly on site. This internal supply chain contained various suppliers, manufacturers, and subcontractors. The supply chain consists of elements with various integration, preparation, standardization and service levels. This sub-structure of the individual work packages was however in most cases opaque to the consultant and to the client.

1.4. Dreamhouse project (Case D)

Dreamhouse was a practical exploration of collaborative design and integration of building systems (see Figure 4). This collaboration ensured the smooth and efficient implementation of the dream-house demonstration project. The project involved four major steps. First, the overall building layouts were categorized into component classification and modular groups. Second, enterprises for each modular group's design and production were selected (see Table 4). Third, a collaborated design was developed and followed by the manufacturing of components. Finally, after the assembly of the space module in the factory, it is transported to the building site as a whole and connected one by one to complete the installation of the whole housing system. The whole assembly process is clear and orderly. About 95% of the project is completed in the factory and the space modules are bolted to facilitate disassembly and reconstruction.



Figure 2. Apartment buildings

Table 2. List of stakeholders participated in the CMC project

Stakeholder Organization	Participant category
Ministry of Urban Development	Client
Building Design Enterprise	Supervisor
CMC & Foster Wheeler Italiana of Milan (Italy)	Designer
CMC	Contractor
CMC	Manufacturer
Local workshops	Special subcontractor
Local suppliers	Supplier



Figure 3. Yi Hui Tang building

Table 3. Collaboration design and construction management partners of the Yi hui tang project

Stakeholders/ Company	Stakeholder position
Southeast University	Designer
Jiangsu Shengle Machinery Co., Ltd.	Client
Jiangsu Yanghu Construction Project Management Co., Ltd.	Supervisor
Jiangsu nigao science & technology co.,Ltd	Contractor
Jiangsu nigao science & technology co., Ltd	Manufacturer
Nanjing Standing Architectural science & technology co., Ltd	Steelwork subcontractor
Jiangsu Golden Lily Door & Window Technology Co., Ltd.	Supplier



Figure 4. Dream-house building

Table 4. Collaboration design and construction management partners of the Dream-house project

Company	Stakeholder position
Southeast University	Designer
Nanjing Standing Architectural science & technology co., Ltd	Client
Jiangsu Yanghu Construction Project Management Co., Ltd.	Supervisor
Nanjing Standing Architectural science & technology co., Ltd	Contractor
CHANGZHOU SHENGLE CONSTRUCTION co., Ltd	Manufacturer
Jiangsu Grerun Ecological Horticulture Technology Co.,Ltd	Special sub-contractor
Suzhou Keyi Residential Equipment Co., Ltd.	Supplier

Supplemental file 2. List of the twenty-eight professionals

Name	Stakeholder position	Stakeholders/ Company	Position in a company	Education	Experience	Address
Asnake Bekele	Client	Depart of Construction and Maintenance, Rental Housing Agency	Head	MSc in Management	35 years	Tito Street, Addis Ababa, Ethiopia
Sileshi Tamru	Supervisor	Building Designer Enterprise	Supervision head	BSc in Civil Engineering	40 years	Queen Elizabeth II Street, Addis Ababa
Wossen Aweke	Designer	Building Design Enterprise	General Manager	MSc in Architecture	30 years	Airport Road, Addis Ababa, Ethiopia
Zewge Mikael	Contractor	EBPPE	General Manage	BSc in Civil Engineering	47 years	Jakros-Salite Mihret Road, Addis Ababa, Ethiopia
Seife Mergia	Manufacturer	Prefabricated Building Parts Production Enterprise, Addis Ababa	Deputy Manager	BSc in Civil Engineering	25 years	Tessema Aba kemaw Street, Addis Ababa
Ashenafi Gebregiorgis	Sub-contractor	Awash construction plc.	Manager	MSc in Civil Engineering	32 years	Jakros-Salite Mihret Road, Addis Ababa
Selamawit Belayneh	Supplier	Yibel Industrial plc.	Sales manager	BSc in Marketing Management	13 years	Ras Mekonen Street, Mexico Square, Addis Ababa
Tadesse Gebregiorgis	Client	Ministry of Urban Development and Housing	Director	MSc Public administration	20 years	Tito Street, Addis Ababa, Ethiopia
Fekadu Yihun	Supervisor	Building Design Enterprise	Director	BSc and MSc in Architecture	33 years	Airport Road, Addis Ababa, Ethiopia
Dario Foschini	Designer	Foster Wheeler Italiana of Milan (Italy)	Director	MSc in Architecture	37 years	Italy, Emilia-Romagna Ravenna 48122, Via Trieste, 76
Massimo Matteucci	Contractor	Cooperativa Muratori Cementisti C.M.C of Ravenna (Italy)	Manager	MSc in Civil Engineering	42 years	Italy, Emilia-Romagna Ravenna 48122, Via Trieste, 76
Behailu Kebede	Manufacturer	Cooperativa Muratori Cementisti C.M.C of Ravenna (Italy)	Production manager	BSc in Business administration	39 years	Ayat, Addis Ababa, Ethiopia
Yidnekachew Walelign	Special subcontractor	Local contractor	Manager	BSc in Construction Management	30 years	CMC street, Addis Ababa, Ethiopia
Tenadam Melese	Supplier	Local supplier	Head	BSc in accounting	13 years	Angola Street, Addis Ababa, Ethiopia
Zhang Lirui	Designer	Southeast University	Ph.D. student	Ph.D. in Architecture	10 years	No.2, Si Pailou, Nan Jing, China
Tang Meng tian	Client	Jiangsu Shengle Machinery Co., Ltd.	CEO	MSc in Business Administration	31 years	No. 8 Dongan Guoye Road, Huangli Town, Wujin District, Changzhou City, Jiangsu Province
Yang Cheng	Supervisor	Jiangsu Yanghu Construction Project Management Co., Ltd.	CEO	MSc in Construction Management	21 years	4th Floor, Hongye Building, West Road, Wujinfu, Changzhou
Liu Cong	Contractor	Jiangsu nigao science&technology co., Ltd	Head	Ph.D. in Architecture	11 years	No. 1 Nigao Road, Bogor Industrial Concentrated Area, Zou District, Wujin District, Changzhou City

Name	Stakeholder position	Stakeholders/ Company	Position in a company	Education	Experience	Address
Zhu Hongyu	Manufacturer	Jiangsu nigao science&technology co., Ltd	Head	MSc in Industrial engineering	10 years	No. 1 Nigao Road, Bogor Industrial Concentrated Area, Zou District, Wujin District, Changzhou City
Liu qingjun	Steelwork subcontractor	Nanjing Standing Architectural science&technology co., Ltd	Department head	MSc in Structural engineering	24 years	Building 2, 300 B Zhihui Road, Kirin Science and Technology Innovation Park, Nanjing
Wu Yanhua	Supplier	Jiangsu Golden Lily Door & Window Technology Co., Ltd.	Salesman	BSc in Marketing management	13 years	No. 9 Road Eging, Jintan, Changzhou, Jiangsu, China
Yingying Zhang	Designer	Southeast University	Ph.D. in Architecture	Ph.D. in Architect	10 years	No.2, Si Pailou, Nan Jing, China
Liu Cong	Client	Nanjing Standing Architectural science&technology co., Ltd	Director	MSc in Architecture	15 years	Building 2, 300 B Zhihui Road, Kirin Science and Technology Innovation Park, Nanjing
Geng Huikang	Supervisor	Jiangsu Yanghu Construction Project Management Co., Ltd.	Site supervisor	BSc in Construction Management	17 years	4th Floor, Hongye Building, West Road, Wujinfu, Changzhou
Zhang Jun Jun	Contractor	Nanjing Standing Architectural science&technology co., Ltd	Department head	MSc in Structural engineering	27 years	Building 2, 300 B Zhihui Road, Kirin Science and Technology Innovation Park, Nanjing
Zhu Hongyu	Manufacturer	CHANGZHOU SHENGLE CONSTRUCTION co., Ltd	Production head	BSc in Civil engineering	23 years	No. 8 Dongan Guoye Road, Huangli Town, Wujin District, Changzhou City, Jiangsu Province
Ding Tao	Special subcontractor	Jiangsu Grerun Ecological Horticulture Technology Co.,Ltd	Head	MSc in Bio-tech Engineering	20 years	Zhangzhuang Village, Xiayi Village, Jiase Town, Wujin District, Changzhou
Gan Yang	Supplier	Suzhou Keyi Residential Equipment Co., Ltd.	Marketing manager	BSc in Marketing management	12 years	Jun Di business center, 3 Wei Hua Road, Suzhou Industrial Park, Jiangsu

Supplemental file 3. List of the ten experts

Name	Experience in IB	Education	Position	Department	Address
Abebe Dinku	42 years	BSc in Civil Engineering, MSc and Ph.D. in Structural Engineering	Professor of Civil Engineering; and Director	Chair of Construction materials and Management at AAU Director Habesha Cement S.CO	Ethio China Friendship Road Addis Ababa, PC 3317
Seife Mergia	25 years	BSc in Civil Engineering, MSc and Ph.D. in Construction Management	Deputy Manager (PC manufacturer)	Prefabricated Building Parts Production Enterprise, Addis Ababa	Tessema Aba kemaw Street, Addis Ababa
Wossen Aweke	30 years	MSc in Architecture	Designer	Building Designer Enterprise	Ethio-China Street, Mina Building, 4 th floor, Addis Ababa
Zewge Mikael	47 years	BSc in Civil Engineering	Manager (contractor)	EBPPE	Jakros-Salite Mihret Road, Addis Ababa
Behailu Kebede	10 years	BSc in Business administration	Manager (PC manufacturer)	Cooperativa Muratorie Cementisti C.M.C of Ravenna (Italy)	Ayat, Addis Ababa, Ethiopia
Hong Zhang	40 years	Ph.D. in Architecture	Professor	Southeast University, China	No.2, Si Pailou, Nan Jing, China
Yingying Zhang	12 years	Ph.D. in Architecture	Designer	Southeast University	No.2, Si Pailou, Nan Jing, China
Liu Cong	11 years	Ph.D. in Architecture	Head of construction (Contractor)	Jiangsu nigao science&technology co., Ltd	No. 1 Nigao Road, Bogor Industrial Concentrated Area, Zou District, Wujin District, Changzhou City
Liu qingjun	24 years	MSc in Structural engineering	Director (Subcontractor)	Nanjing Standing Architectural science & technology co., LTD	Building 2, 300 B Zhihui Road, Kirin Science and Technology Innovation Park, Nanjing
Tang Meng tian	31 years	MSc in Business Administration	CEO (Client)	Jiangsu Shengle Machinery Co., Ltd.	No. 8 Dongan Guoye Road, Huangli Town, Wujin District, Changzhou City, Jiangsu Province

Supplemental file 4. Evaluation for indicating factor for SCM

The aim of this questionnaire is to quantify the stakeholder's collaboration management (SCM) relationship

strength for all project cases based on the factors of the collaboration relationship mentioned below.

Evaluation form: please tick on the range of the 5 options given for the evaluation of factors of stakeholders' relationships for the respective projects.

For the collaboration relation of client and designer	Data sources	Evaluation criterion	Evaluation
Evaluation factor		Evaluation criterion	Evaluation
Frequency and intensity of communication	Chapman and Corso (2005), Antoncic and Prodan (2008), Xue et al. (2018a)	5 – Frequently (1–2 times a week), 4 – Sometimes (1–2 times a month), 3 – Occasionally (1–2 times a half-year), 2 – Hardly (except when accidents or specific events occur), 1 –Never	1. N 2. N 3. N 4. N 5. N
Contractual relationship	Jalal and Koosha (2015), Xue et al. (2018a, 2018b)	5 – Contractual relation, 4 – Instruction relation, 3 – Coordination relation, 2 – information exchange relation, 1 – Not direct relation	1. N 2. N 3. N 4. N 5. N
Length of time to work together	Antoncic and Prodan (2008), Rutten et al. (2009), Xue et al. (2018b)	5–80 – 100%; 4–60 – 80%; 3–40 – 60%, 2–20 – 24%, 1–0 – 20%	1. N 2. N 3. N 4. N 5. N
Depth of exchange of technologies, resources, and information	Golob et al. (2013), Xue et al. (2018a)	5 – Must, 4 – Should, 3 – Can, 2 – Maybe, 1 – No	1. N 2. N 3. N 4. N 5. N

Please note that the evaluation shall be done for every two of the stakeholder's relationship, i.e., client-designer, designer-manufacturer, PC manufacturer-contractors, supplier-contractors, contractors-supervisor, supervisor-special subcontractor, client-contractors, client-manufacturer, client-supplier, client-supervisor, client-special subcontractor, designer-special contractors, designer-contractors, designer-supplier, designer-supervisor, designer-special subcontractor, PC manufacturer-supplier, PC manufacturer-supervisor, PC manufacturer-special subcontractor, supplier-supervisor, supplier-special subcontractor, contractor-special subcontractor).

Supplemental file 5. Evaluation of the driving factor for SCM

The aim of this interview/questionnaire is to quantify the importance level of the driving factors of stakeholders collaborative management (SCM) based on the listed layout from the literature review.

Range the drivers of stakeholder collaborative management using a five-point scale: 1 – not important, 2 – important, 3 – more important, 4 – very important and 5 – most important. Please make a '√' sign in the box for the appropriate importance level of the driving factor.

Please add or reduce the driving factors that you think is necessary or unnecessary.

Driving factors	Evaluation range				
	1	2	3	4	5
Design-construction efficiency					
Minimize cost					
Quality improvement					
Save time					
Encourage innovation					
Strengthen alliance and cooperation					
Information and resource transfer					
Expand market					
Technical barriers					
Enhance competitiveness					

Supplemental file 6. Evaluation of factors for DCE of project cases

The aim of this interview/questionnaire is to quantify the importance level of the component factors of design-construction efficiency (DCE) based on the listed layout from the literature review.

Range the drivers of stakeholder collaborative management using a five-point scale: 1 – not important, 2 – important, 3 – more important, 4 – very important and 5 – most important. Please make a '√' sign in the box for the appropriate importance level of the driving factor.

Dimension	Indicators	Case A	Case B	Case C	Case D
Design – Construction efficiency	Integrated design (ID)				
	Integrated construction (IC)				
	Integrated management (IM)				
	Construction schedule (CS)				
	Average (mean)				

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