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Development of Tool for Measuring Flexibility of Building Construction Projects

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Abstract: The paper aims to propose a novel tool in the form of a questionnaire that will measure flexibility of building. The tool designed to measure the flexibility of building will help in identifying flexible building structures. In the recent past the importance of flexibility and adaptability in construction building projects has increased. The reason for it can be rapid change and involvement of both private and public organizations in construction projects, new ways of working where client is asking for more innovative and flexible work place designs, high renovation costs due to changing user demands and more focus on the environmental costs. A survey method including experts from construction industry is used for this work to design a tool that can measure the flexibility of buildings. Flexibility becomes inevitable for environment where the environment is dynamic. For a ready adaptation to market fluctuations it would be good to impose the condition that the building, along with its installations should be suitable for several uses. The flexibility measurement tool will help the construction practitioners for achieving flexible building structures for the continuous changing demands. Prior research work contains various characteristics of flexible building structures but no attempt has been made to develop a questionnaire for measuring flexibility of buildings.

Keywords: Construction Projects; Flexibility; Technical Installations; Flexibility Measure

1. Introduction

The only thing that is permanent in the world is change. Change is a process of the transition from past to present, and to the future. Inspire of this fact most planning processing focus on present situation and short term tradeoffs rather than the distant future. In the recent past the importance of flexibility and adaptability in construction building projects has increased. The reason for it can be rapid change and involvement of both private and public organizations in construction projects, new ways of working where client is asking for more innovative and flexible work place designs, high renovation costs due to changing user demands and more focus on the environmental costs and effects of obsolescence, (Saari et al. 2006).

Construction projects are built with specific goals like, educational buildings, hospitals, offices, houses, etc where the requirement of each project is very specific. Depending on how well they serve their purpose, buildings contribute to efficiency, effectiveness, and satisfaction for their occupants. Building projects can be related as objects that will last for decades, sometimes even for centuries. Although buildings are built to last long, still we notice changes in buildings. There are many things that happen to a building depending on the changing requirement. Some buildings are demolished and new ones are constructed, some are maintained, some are extended, some are renovated. All buildings are subject to change. Sometimes these changes are carried out in order to maintain and repair the building, but more often it comes because of the change in the user or the occupant. For example it may happen that an owner of a hospital building has sold his property to a person who is interested in building a hotel over there. Changes in these businesses are becoming more frequent. One of these demands is that the building should be able to change and adapt to support the changes in organizations. It is because of the changing user demand and the more environment friendly ways of constructing and using buildings, the construction projects require a new way of life-cycle phasing of buildings, (Smith & Oltman, 2011). Thus there is some or the other uniqueness in each construction project due to which change in the construction process is inevitable on most construction projects.

2.0 Literature Review

Change is defined as any event or situations that results in a modification or alterations of the original scope, execution time, or cost of work, (Hanna et al 2002). Such changes occur on a project for many reasons, such as design errors, design changes, additions to the scope, or unknown conditions. Each such change has a high impact on the original cost and schedule of the project, (Hanna et al 2002). In most of the industries where there is a stable environment the changes are predictable and are not frequent. Due to which the critical variables can be identified and a plan can be developed for the same. However, in extremely turbulent and dynamic environments like construction industry where change is frequent and unpredictable, it becomes difficult to go through the routine process and follow the plan. Hence flexibility becomes inevitable for such environments (Volberda 1997).

Making flexible arrangements in managing projects is not a new concept. Many studies show that to bring out the effects of uncertainty in planning, the project plan should be made flexible. But the practicability of this concept is not yet established empirically. Olsson (2006) observed in his empirical study of 18 Norwegian projects that as per the stakeholders, flexibility in the initial phase of the project life cycle is noncontroversial. There are examples of many projects where changes were made in spite of the foolproof planning and risk for cost overruns (Pundir, et al, 2008). Hence if during the whole period of the projects room for flexibility is given, it will surely be utilized. Cui and Olsson (2009) studied 82 public investment projects in Norway and found that if there is more uncertainty in project, it is more difficult to estimate how project planning can be applied in future. Due to the increasing complexity and dynamics in the environment of organizations, changes are required more frequently. The growing use of new technologies in front office and in back office of organizations is often considered as a main cause of complexity (Lehmann, 2010). Lehmann (2010) has made an attempt to establish relationship between project management and change management and tried to incorporate the assumptions of change management in the field of project management. The field of project management is not yet explored as it should have been and the concepts of management are not fully implemented in the area of project management. Hence it is seen from the literature that the projects are ready to adapt the changes, but the scrutiny of the theory and the practicability of the concept need to be tested. Cooper and Lyneis (2002) discussed some of the reasons behind the failure to systematically learn from the past project experiences, and presented an approach and framework for cross-project learning. As per the traditional thinking, construction projects are built for specific users whose requirements are well known in advance. Similarly, it has been assumed that users are able to define all their requirements during the project design stage and that, being aware of the details, they can thus approve the design solutions presented to them on paper. Large building construction projects are planned from 5 to 10 years in advance, and are typically designed to have a lifespan of more than 40 years. During this time, demands on the infrastructure are likely to change significantly. Although certain flexible solutions are repeated from one project to the next, no serious thought is given to making flexible allowances for the potentially different needs of future users of the building, (Patrizi et al, 2006). Flexibility is a property of a building that is realized to some extent in all projects, even if it had not been actually taken into account during the design phase. Saari & Heikkila, (2006) discussed that flexibility has been perceived as an ambiguous, immeasurable concept. Moreover, it means different things to different interest groups. The user is typically interested in the flexibility of the spaces used in daily activities whereas the owner is interested in flexibility over the medium and long term, (Saari & Heikkila 2008). Unconsidered investment of resources in flexibility may lead to unnecessary expenditure that does not necessarily result in flexibility in connection with actual changes. On the other hand, rigid design solutions may increase dissatisfaction among users, (Smith & Oltman 2011). Flexibility can be affected most effectively by controlling design and construction. When the building is finished, the possibility to have an impact on its flexibility is much more constrained since it is implemented through frame solutions, floor heights, building services ductwork, etc. which are expensive to change afterwards. Thus, flexibility is a key parameter in the building construction business, (Blakstad 2001).

The user is interested in a different type of flexibility than the building owner. The different types of flexibility of building as given by Saari and Heikkila, (2008) are:

Service flexibility: This type of flexibility means how much a building can adapt to repeated quick changes in loading. A change in loading means change in the number of people who are using that space, changes in the occupancy of the space, etc. Service flexibility can be improved by, for instance, movable partitions and adjustable ventilation, (Saari and Heikkila, 2008).

Modifiability: Modifiability of a building is the ability to meet the changing requirements of its occupants, for instance, from hotel to education business. (Saari and Heikkila, 2008)

Long-term adaptability: Long-term adaptability of a building refers to the adaptability of a building to requirements that are not specified and unknown. Old industrial properties have been particularly adaptable into offices and residential use only because of having long term adaptability in terms of high floor heights and long spans, (Saari and Heikkila, 2008).

Clear phasing of the design process facilitates consideration of flexibility in the construction process. Designers and implementers offer universal technical solutions which they regard as flexible, (Blakstad et al, 2009). The solutions offered by designers may vary as to flexibility by fields of design. The architect's space arrangement may allow a quite large flexibility, but, for instance, the principle of air distribution might not allow changes in the room plan without major changes in building services technology. (Gereadts, 2008).

2.1. Tool for measuring flexibility in building construction

How much flexible or adaptable a building is? This is a basic question which needs to be answered. Finding a flexibility measure of a building could help in knowing the adaptability or flexibility of a building. It can be calculated as, (Blakstad, 2001):

Flexibility measure (%) = 1 – [renovation cost / new construction cost]

If the flexibility measure of any building is more it means that the building is more adaptable for new occupancy.

There is an increasing pressure on society to develop and construct sustainable buildings. Hence the flexible buildings and installations that are adaptable to changing conditions is the need of present society. Adaptable, recyclable and sustainable buildings will be major criteria in assessing performance of future buildings. Among the factors that play a role in performance measurement are saving of base materials, minimizing waste production, ease of dismantling and adaptability. (Paslawski, 2008)

3. Designing of Tools for Measuring Flexibility of Buildings

The technical installations (electrification, plumbing, mechanical, etc) are the key factors with respect to the possibilities of adapting buildings. Installations often prove not to be sufficiently flexible to follow changes in their use without too many adaptations. Therefore flexibility measurement tool for installations could be regarded as a tool for assessing and discussing flexibility of a building as a whole in a rapidly changing market, (Gijsbers 2008). For a ready adaptation to market fluctuations it would be good to impose the condition that the building, along with its installations should be suitable for several uses. It is important that construction and installation components can be easily disconnected or removed. The following are some of the variables that can be used for the assessment of flexibility of building as shown in table 1. These variables are selected from many research works cited above in the literature review section above, mainly including (Saari and Heikkila, 2008), (Gereadts 2008), (Blakstad et al, 2009), (Blakstad, 2001).

Table 1. Variables used to measure Flexibility

S.N.	Variables	Abbreviation	References
1	Extendible	(EXT)	(Blakstad et al, 2009), (Gereadts 2008)
2	Rearrangable	(REG)	(Gereadts 2008), Volberda (1997)
3	Movable	(MOV)	(Gereadts 2008), (Blakstad , 2001)
4	Disconnectable	(DIC)	(Gereadts 2008)
5	Universal	(UNI)	(Saari and Heikkila, 2008)
6	Ejectable	(EJC)	(Gereadts 2008), (Hanna et al 2002)
7	Expandable	(EXD)	(Saari and Heikkila, 2008)
8	Exchangeable	(EXC)	(Gereadts 2008), (Gijsbers 2008)
9	Dismountable	(DIM)	(Gereadts 2008), (Gijsbers 2008)
10	Partitionable	(PAR)	(Gereadts 2008), (Paslawski 2008)

11	Shapable	(SHP)	(Blakstad et al, 2009), (Gereadts 2008)
12	Dismantelable	(DIS)	(Blakstad et al, 2009), (Gereadts 2008)
13	Multifunctional	(MUL)	(Saari and Heikkila, 2008)
14	Adaptable	(ADA)	(Saari and Heikkila, 2008), (Blakstad 2001)
15	Dividable	(DIV)	(Gereadts 2008), Patrizi (2006)
16	Combining	(COM)	(Blakstad et al, 2009), (Gereadts 2008)
17	Alterable	(ALT)	(Saari and Heikkila, 2006), (Blakstad 2001)
18	Zonable	(ZNB)	(Gereadts 2008), (Olsson 2006)
19	Modular	(MOD)	(Olsson 2006), (Blakstad et al, 2009)
20	Adjustable	(ADJ)	(Saari and Heikkila, 2008)

A questionnaire consisting of close ended questions was prepared based on the above 20 variables for measuring flexibility of a building. The questionnaire is prepared using English language and the sentences used are short and simple to improve the response rate.

3.1 Design of Questionnaire

Based on the above factors and the variables related to those factors the questionnaire for measuring flexibility of a building is designed. The main purpose of the questionnaire is to produce a tool that can measure flexibility of a building. The questionnaire consists of 20 items (variables), which include 20 questions on given variables. The items relate to almost all the relevant factors that brings flexibility of building. All the questions are direct and positively keyed. A five point Likert scale was used from 1 to 5, 5 being the maximum score for each question and 1 being the minimum score for each question.

4. Pilot Study

In order to test how long it takes to complete the questionnaire, and to check that all questions and instructions are clear and to expose any items that will not generate usable data, pilot study was carried out with a sample size of 20, which includes 4 site engineers, 8 architects, 4 project managers and 4 academicians. The academicians were from the department of civil engineering and department of architecture from a renowned institution in Nagpur, India. The site engineers, architects, and project managers were from a well known construction group in Nagpur.

4.1 Validity and Reliability

Content and face validity was assessed by the 20 members selected for the pilot study who commented on the clarity of items, and content in terms of factors related to measurement of flexibility of building. Since it was a pilot study, the 20 members were encouraged to ask questions, to give remarks and identify missing concepts. The purpose of the tool was explained to them clearly. The team was asked to comment on the concept and clarity of questions. Some suggestions were given by the pilot study members which included duplication of items and ambiguity in some questions. Based on their suggestions modification were made in the questionnaire.

To check the questionnaire reliability analysis of the flexibility questionnaire was done using the most common index of reliability, namely, Cronbach's coefficient alpha (α).

The reliability analysis for the questionnaire was done using SPSS, the result of which is shown in table 2.

Table2. Reliability analysis of the questionnaire using SPSS version 16

Reliability Statistics

Cronbach's Alpha (α)	Cronbach's Alpha Based on Standardized Items	N of Items
.842	.886	20

A commonly accepted rule of thumb is that score above 0.70 is considered acceptable, (Nunnally & Bernstein, 1994). The Cronbach alpha for the items of the questionnaire was 0.84 that showed sufficient internal consistency among the items of the questionnaire. This makes the questionnaire ready to be used for the further study.

4.2 Factor Analysis

In order to reduce the variables and to check the integrity of the flexibility scale, an exploratory principal component factor analysis is done on the 20 flexibility variables. The scree plot for the factor analysis is given below in Fig1. The result of which showed four components (factors) accounting for 90% of the cumulative variance as showed in table 3 below.

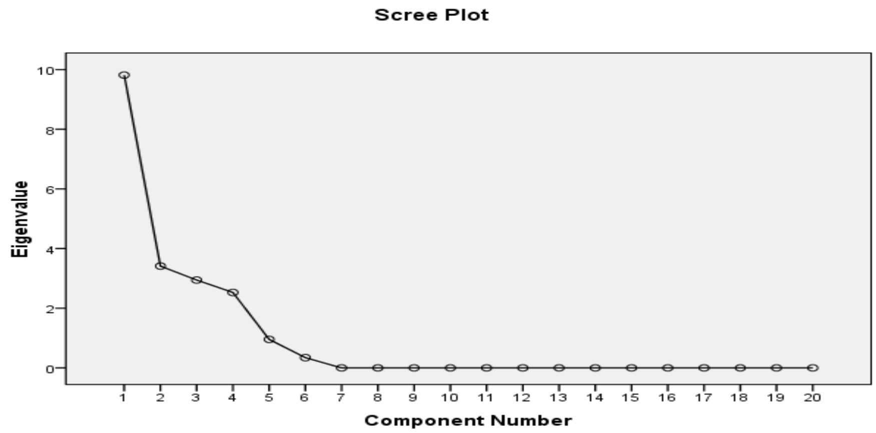

Figure 1 Scree plot showing the clear grouping of four components

Table 3. Factor Analysis Table

	Rotated Component Matrix(a)			
	Component			
	1	2	3	4
Extendible	**0.92**	0.134	0.164	0.187
Rearrangable	0.235	0.128	0.152	**0.847**
Movable	0.13	**0.955**	0.122	0.196
Disconnectable	0.193	**0.844**	0.104	0.208
Universal	0.059	0.102	**0.55**	-0.081
Ejectable	**0.85**	0.134	0.164	0.187
Expandable	**0.9**	0.134	0.164	0.187
Exchangable	0.133	**0.702**	0.081	-0.19
Dismountable	**0.89**	0.134	0.164	0.187
Partitionable	0.235	0.128	0.152	**0.947**
Shapable	0.13	**0.875**	0.122	0.196
Dismantelable	0.193	0.107	**0.699**	0.208
Multifunctional	0.164	0.134	**0.82**	0.187
Dividable	0.235	0.128	0.152	**0.779**
Adaptable	0.13	**0.89**	0.122	0.196
Combining	0.193	0.107	**0.589**	0.208
Alterable	**0.959**	0.134	0.164	0.187

Zonable	0.235	0.128	0.152	**0.727**	
Modular	0.13	0.196	0.122	**0.831**	
Adjustable	0.193	0.107	**0.788**	0.208	
Extraction Method: Principal Component Analysis.					
Rotation Method: Varimax with Kaiser Normalization.					
a. Rotation converged in 5 iterations.					

Table 3 shows the factor analysis. When extracted using principal component analysis and rotated to simple structure using Varimax rotation, four clean factors were apparent from the matrix loadings. The variables in the group are then correlated in order to find the association between the variables of the same group. The correlation matrix showed that there was a significant correlation among the five variables falling within one component. The association between rearranging (REG) and zonability (ZNB) was (r= 0.34, p=0.0001) as shown in Table 4.

Table 4. Correlation matrix of one component variables

Correlation Matrix

		REG	PAR	ZNB	MOD	DIV
REG	r	1				
	sig. (1 tailed)					
PAR	r	0.452*	1			
	sig. (1 tailed)	0.001				
ZNB	r	0.34**	0.370*	1		
	sig. (1 tailed)	0.0001	0.0001			
MOD	r	0.254*	0.210*	0.452*	1	
	sig. (1 tailed)	0.002	0.015	0.001		
DIV	r	0.169*	0.321**	0.254*	0.254*	1
	sig. (1 tailed)	0.019	0.0001	0.001	0.002	

r = Pearson Correlation

* Correlation is significant at 0.05 level

** Correlation is significant at 0.01 level

According to the existing literature of variables related to flexibility measurement and after discussing with the pilot study members these four factors can be designated as following based on the result and grouping of factor analysis and correlation analysis:

- **Partitionability** (which includes Rearranging, Dividable, Zonable, Modular);

- **Adaptability** (which includes Movable, Disconnectable, Shapable, Exchangeable);
- **Extendibility** (which includes Ejectable, Expandable, Dismountable, Alterable);
- **Multifunctionality** (which includes Universal, Dismantelable, Combining, Adjustable).

The factors are further explained as follows:

Partitionability: It is easy splitting up, rearranging or combining of installation systems into different spatial units. To determine the degree of partitionability of a building the following variables are used, (Gijsbers 2008)

- Rearrangable;
- Dividable;
- Zonable;
- Modular.

Adaptability: This involves alterations in the building units to meet the changes in the user demands that results from structural or functional rearrangement of the building, from changes in use, the change in occupancy, or technological renewals and modernizations considered necessary. To determine the degree of adaptability of a building the following variables are used, (Blakstad et al, 2009)

- Movable;
- Disconnectable;
- Shapable;
- Exchangeable.

Extendibility: It is meeting the additional user demands by adapting installation systems, for instance by the addition of more or new installation components by structural or functional extensions, both inside and outside the existing building. To determine the degree of extendibility of a building the following variables are used. (Saari & Heikkila 2008)

- Ejectable;
- Expandable;
- Dismountable
- Alterable

Multifunctionality: It is the possibility of using installation systems or components for multiple functions. This allows of a more efficient use of space and permits clustering and concentration of installation components. To determine the degree of multifunctionality of a building the following variables are used. (Gereadts 2008)

- Universal;
- Dismantelable;
- Combining;
- Adjustable.

5. Conclusion

Flexibility is a property of a building which is very relative. Flexibility cannot be a universal property of a building. Thus, no universal aims and goals can be set for flexibility in building structures nor can "absolutely flexible" building be built. There is a need to determine which alternative uses / situations the builder should prepare for since it is not possible, in practice, to be prepared for an arbitrary change. Likewise, construction managers must estimate acceptable conversion costs and disturbances to activities. The proposed tool to measure the flexibility of building may help in identifying flexible building structures. This Flexibility measurement tool for installations could be regarded as a tool for assessing and discussing flexibility of a building as a whole in a rapidly changing market. For a ready adaptation to market fluctuations it would be good to impose the condition that the building, along with its installations should be suitable for several uses. It is important that construction and installation components can be easily disconnected or removed. This definitely will help us for preparing ourselves for the "unknown future" mainly by flexible solutions related to the building structure.

6. References

Blakstad H.S., (2001). A Strategic Approach to Adaptability in Office Buildings. *Doctoral Thesis*, Norwegian University of science and technology, URN: NBN: no-2306.

Blakstad H.S., Hansen G.K., Knudsen W. (2009). Methods and tools for evaluation of usability in buildings. SINTEF / NTNU, Norway.

Cooper R.G., Lyneis J.M., Bryant B. (2002). Learning to learn from past to future. *International journal of project management*, Vol 20, No 3, pp 213- 219.

Cui Y., Olsson N., (2009). Project flexibility in practice: An empirical study of reduction lists in large governmental projects. *International journal of project management*, Vol 27, No 3, pp. 447- 455

Hanna A, Peterson P, Camlic R, Nordheim E (2002). Quantitative definition of projects impacted by changes. *Journal of Construction Engineering and Management*, Vol. 128, No. 1, pp. 57-64.

Geraedts, R.P. (2001). Costs and benefits of flexibility. *In proceedings World Building Congress*, Wellington, New Zealand.

Gijsbers R. (2008). A new approach to flexibility in use adaptability of structural elements. *Journal of Department of Architecture*, University of Technology, Eindhoven, The Netherlands, Vol 1, pp 23-32.

Lehmann V. (2010). *Connecting changes to projects using a historical perspective: Towards some new canvases for researchers*. Vol 28, No 2, pp 328- 338.

Nunnally J., Barstein I., (1994). *Psychmetric Theory*, third edition. New York: MC Graw Hill.

Olsson N., (2006). Management of Flexibility in Projects. *International Journal of Project Management*, Vol 24, No 3, pp. 66 – 74.

Paslawski J. (2008). Flexibility approach in construction process engineering. *Technological and Economic Development of Economy*, Vol 14, No 4, pp 518–530.

Patrizi P.A., Gross E.K., Freedman S. (2006). Strength in flexibility: Lessons from a cluster of capacity building grants in the juvenile justice field. *Evaluation and Program Planning*, Vol 29, pp. 162–170.

Pundir A. K., Ganapathy L., Sambandam N. (2008). Some approaches to managing flexibility in construction projects. *Global journal of flexible systems management*, Vol 9, No 1, pp 23- 29.

Saari A., Heikkila P. (2006). Flexible building management. *The Open Construction and Building Technology Journal*, Vol. 1, pp. 142-151.

Saari A., Heikkila P. (2008). Building Flexibility Management. The Open Construction and Building Technology Journal, Vol. 2, pp. 239-242

Smith P., Oltman J. (2011). Flexible Project Management. *PM world today*, Vol. 13, Issue 2, pp. 1-6.

Volberda H. (1997). Building flexible organizations for fast moving markets. *Long Range Planning*, Vol. 30, No 2, pp. 169-183.