



Assessment of Safe Egress Time calculations for Performance-Based Fire and Life Safety designs

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Abstract— Uncertainty of safe egress time is an inherent problem during performance-based fire safety design. The two central concepts of performance-based design, ASET (available safe egress time) and RSET (required safe egress time), are separate degrees of freedom, each of which can be optimized to achieve performance objectives. Hence, development of a proper method of egress time estimation and improving accuracy of calculations by incorporating the risk tolerance is essential. The purpose of this research is to introduce a conceptual model of human behavior in fire. This model is based upon a theoretical framework of individual decision-making and response to emergencies, and from this foundation, is populated with behavioral statements or mini-theories predominantly from human behavior in fire. From these studies, the occupant characteristics are listed in terms of parameters to be used as input to the final evacuation models, that shall be simulated using a suitable software.

The primary research is then carried out on a case study, where the occupants are surveyed and their characteristics are recorded. The results are inputted into a suitable simulation platform. The evacuation simulations are then performed for different cases, and are compared to record the deviation in the safe egress time graphs, as per current method, and when occupant characteristics are considered. The delays calculated from the simulations, are further validated against a real case scenario, from the secondary study, and conclusions are drawn on how to reduce the risk tolerability in performance-based fire and life safety designs.

Keywords— Evacuation time, Performance Based Design, ASET, RSET Occupant Behavior

I. INTRODUCTION

The primary concern during fire emergency is to evacuate persons to a secure location to reduce casualties. Successful evacuation of all occupants from a building depends on several factors like number of exits, maximum width and length of the escape routes, signage & lighting system, maximum time for evacuation, managerial strategies to remain escape routes available & safe etc (Farooqui, Jain, Shashi, Kumar, & Singh, 2011). Uncertainty of safe egress time is an inherent problem during performance-based fire safety design. The two central concepts of performance-based design, ASET (available safe egress time) and RSET (required safe egress time), are separate degrees of freedom, each of which can be optimized to realize performance objectives (Averill, Reneke, & Peacock, 2015).

For performance-based codes, the foremost important challenge is to define the standards to fulfil the code compliance and thus the required tools to quantify these criteria (Hadjisophocleous, 2005). A model is simply successful if it considers egress design as a function of occupant behaviour, instead of assuming robotic movements, as is prevalent in most existing computer models. So, proper research is required for inclusion of risk factors in safe egress designs.

Hence, development of an accurate method of egress time estimation and improving accuracy of calculations by incorporating the danger tolerance is crucial. Prescriptive fire safety designs comprise a deterministic model built on the collective experience of the fireside safety profession, obtained through endless process of trial and error. Performance based designs, on the alternative hand, provide a case specific unique solution, and inclusion of behavioral traits and Probabilistic risk assessment could also be a necessary methodology to demonstrate adequate safety in such designs (Mohan, 2019).

1.1 Aim of the Study

To critically analyze the methodology for Safe Egress Time calculations in Performance based Fire and Life Safety Designs, considering occupant characteristics that may have a bearing on its reliability.

1.2 Research Questions & Objectives

The primary research question in this paper “How to incorporate occupant behaviors during a fire emergency into egress models?” and in order to answer this research question and achieve the aim of the study, the following research objectives were set:

1. To develop an understanding of the design process for Performance-based Fire Safety designs, to identify the gap in current method.
2. To develop a method to incorporate behavioral patterns in egress calculations through the study of behaviour theories and occupant movement patterns during egress.
3. To develop data collection parameters for the evacuation model, and perform simulations to calculate safe egress time for a structure.
4. To compare the egress time between evacuation models using a simulation platform and validate.

1.3 Research Methodology

The initial objectives of this research shall be achieved through study of existing literatures on performance-based design to identify the gaps in the method of calculation of Egress times; followed by the review of literature on behavioral patterns in egress and various methods of incorporating it into a design model. Then, a case study shall be selected, where an occupant shall be carried out. This survey shall be designed from the literature review inferences, and it shall determine the parameters to be used in the simulation of the egress model. Finally, the derived values from survey shall be incorporated into the egress model and computer simulation shall be carried out to determine the occupant related delays in egress.

II. DESCRIPTION OF TOPIC

2.1 Performance-based designs

Performance-based design is often implemented in one among two methods: (1) as a way to work out equivalency to a prescriptive code or standard, or (2) as an approach to attain broadly defined fire safety goals and objectives. Performance based designs provide a case specific unique solution, and inclusion of behavioral traits and Probabilistic risk assessment could be a necessary methodology to demonstrate adequate safety in such designs (Mohan, 2019).

There are five stages of fire: Ignition, Growth, Smoke & Heat propagation, Egress and Extinguishment. The time between flame spread and evacuation of occupants to a secure area is where the fire safety focuses on. In real fire scenarios, evacuation time is usually preceded by a delay called the pre-movement time.

2.2 Behaviour Theories and Occupant Movement During Egress

This list of behavioural statements provides our current understanding of human behaviour in fire, and when organized using the PADM, the event of a conceptual model is feasible. The representation of those statements within a computational environment will allow their impact on performance to be represented, but may act as a workplace to further refine the conceptual model itself. There are 2 main difficulties in building a sensible agent-based model of human behaviour: finding the proper balance between model description (realistic enough to accurately describe and generate believable human behaviour for every agent) and complexity (yet simple enough for its results to be easily understandable) (Edmonds & Moss 2005; Adam & Gaudou 2016); and finding and exploiting data to tell the model.

2.3 Methods Used by Evacuation Models to Simulate Human Behaviour

2.3.1 Technique 1: The behaviour is defined entirely by the user

- User defines the behaviour for a personal or a gaggle.
- The user assumes that the behaviour is probably going to occur (or even that it'll definitely occur) at some point during the simulation.
- E.g.: Simulex

2.3.2 Technique 2: The behaviour is simulated supported a particular condition (if-then)

- To simulate a known behaviour when the occupant encounters a particular condition.
- Based on “if, then” statements; meaning that if an occupant encounters X, then s/he or the group will do Y.
- User continues to be involved in enabling the potential of the “if, then” statements or perhaps identifying the condition which will (probabilistically) or will (deterministically) prompt the action to occur.
- The evacuation model and also the user play a task in simulating behaviour.
- E.g.: Building Exodus, Pathfinder.

2.3.3 Technique 3: The behaviour is simulated supported multiple factors of influence

- Simulated actions are just like those in Technique 2 (e.g., choosing a route, turning back, helping others, and shutting doors), but these actions are individually chosen for occupants supported a series of things.
- Factors can include information that the occupant knows before the hearth, what information is gathered during the event, and what others know within the building.
- The user’s role during this technique involves providing occupant threshold values for several of the factors, like crowding factors, initial knowledge of the most effective exits, smoke tolerance, and preference levels, like preference to attend, crowding, etc.
- E.g., Building Exodus

III. CASE STUDY

The parameters required for simulation have been converted into quantifiable data points. But, since all data is not possible to be collected from primary sources, some shall be extrapolated from secondary sources like existing demographic surveys, studies, etc.

Occupant Characteristics		Building Characteristics		Fire Characteristics	
Profile	<ul style="list-style-type: none"> • Gender • Age • Ability • Limitation 	Occupancy	Defined (Hotel)	Visual Cues	<ul style="list-style-type: none"> • Flame • Smoke • Deflection on surfaces
Experience	<ul style="list-style-type: none"> • Familiarity to space • Past Experience • Past Training 	Architecture	<ul style="list-style-type: none"> • No. of Floors • Floor Area • Exit location • Stairwell location • Geometry • Visual access 	Olfactory Cues	<ul style="list-style-type: none"> • Burning Smell • Acrid Smell
Condition	<ul style="list-style-type: none"> • Alone/ In Group • Active/ Passive • Alert • Under Influence (Intoxicants/ Medication) 	Activities	<ul style="list-style-type: none"> • Working • Sleeping • Eating 	Audible Cues	<ul style="list-style-type: none"> • Cracking • Broken Glass • Objects Falling
Role	<ul style="list-style-type: none"> • Visitor • Employee 	Fire Design	<ul style="list-style-type: none"> • Fire Alarms • Trained Staff • Refuge Area • Suppressants 	Sensory Cues	<ul style="list-style-type: none"> • Heat

Table 1: Parameters for Case Study

3.1 Project Details

- Project: ITC Royal Bengal,
- Location: Kolkata, West Bengal
- Year of Completion: 2019
- Building Height: 128m (420ft)
- No. of Floors: 30 (plus 2 basements)
- Floor Heights: 7.5m, 3.6m
- No. of Rooms: 456

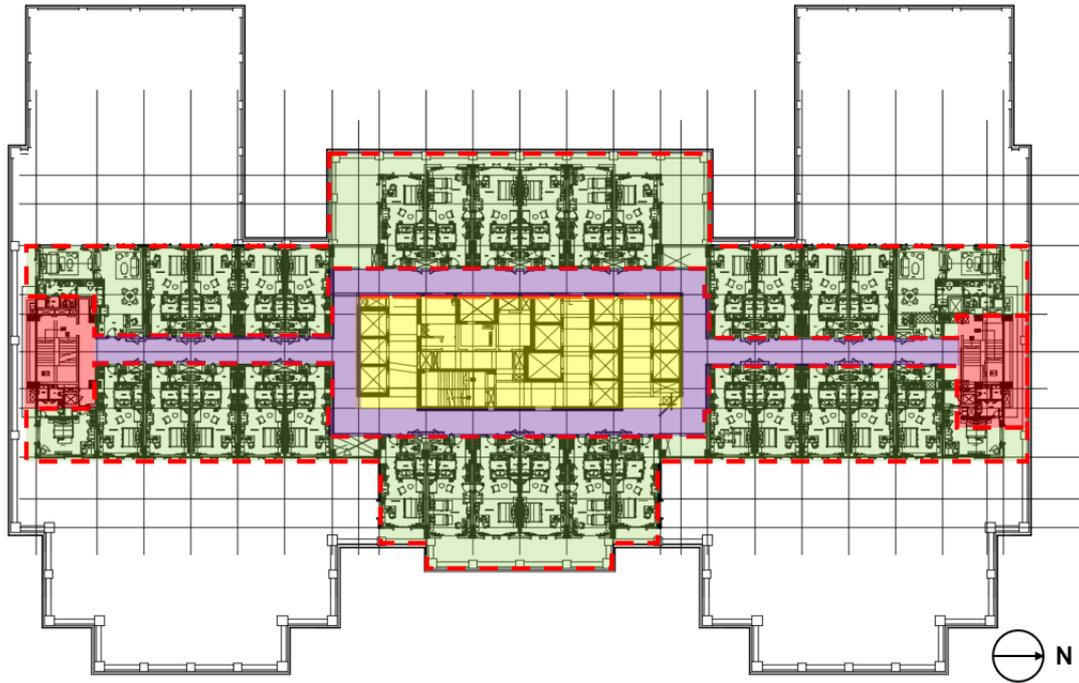


Figure 1: Typical Floor Plan, ITC Royal Bengal, Kolkata

3.2 Case Study Analysis

As per learnings of secondary study, the value of RSET is supposed to increase for each case as,

- Manual calculations do not account for all pre movement delays, ignore delays in turning radii for change in movement directions, collisions for congestion at exit points, familiarity of occupants, social dynamics of group movement, and many such behavioural factors. Hence, the value of RSET is much lower.
- In case of a software Simulation of egress, without inputting case specific behaviour data, geometric factors like ignore delays in turning radii for change in movement directions, collisions for congestion at exit points, are accounted for. But, since behaviour profiling is not done, it considers uniform movement speeds and pre movement delays for all occupants, which is never the real case.
- So, when the simulation is done through profiling the occupants, all behavioural delays in RSET, like familiarity of space of occupants, social dynamics of group movement, non-uniform movement speed and pre movement delays, can be accounted for.

Choice of tool for analysis: PATHFINDER

For the case study analysis, data points were collected through a occupant survey, as per the categories discussed. The 5 sets of data were collected to minimize errors, and the results were extrapolated and used for simulation. A model questionnaire has been presented here.

Role: Visitor			
1	Profile		
1.1	Gender	M	
		F	
1.2	Age group	Less than 20	
		20-50	
		Above 50	
2	Experience		
2.1	Familiarity to space: Choice of Exit	Familiar exit	
		Nearest Exit	
		Follow others	
		Follow emergency exit signs	
		Others	
2.2	Past Experience of Emergency Evacuation due to fire	Y	
		N	
3	Condition		
3.1	Pre-movement Delay: First Reaction on hearing the alarm	evacuate immediately	
		collect belongings	
		help others	
		others	
3.2	Unavailability or Obscurement of route	Wait	
		Press forward	
		Look for another route	
		Others	
Role: Employee			
1	Profile		
1.1	Gender	M	
		F	
1.2	Age group	Less than 20	
		20-50	
		Above 50	
2	Experience		
2.1	Past Training	Y	
		N	

Table 2: Case Study Survey Sheet

All data received from the case study surveys have been incorporated into the simulation model. These percentages are extrapolated to fit the actual population size in the pathfinder model. The population size is derived from actual capacity of the facility and corrected according to occupancy percentage of annual data. Some data, which could not be collected from survey, like ranges for pre movement delays, have been derived from literature, and used in the model simulation.

Conditions	PD7974		SFPE	NFPA		CIBSE GUIDE
	T1*	T2*		Origin	Remote	
Occupants are Awake and Unfamiliar with the building						
Voice Alarm Signal/Trained Staff assisted evacuation	0.5	2	<2	0.5	1	3
Standard Alarms throughout the building	1	3	3	1	2	
Local Alarm and Non-trained Staff	>15	>15	>6			
Occupants are Sleeping and Unfamiliar with the building						
Voice Alarm Signal/Trained Staff assisted evacuation	15	15	<2	1	5	20
Standard Alarms throughout the building	20	20	4		10	
Local Alarm and Non-trained Staff	>20	>20	>6			

*Notes: All Values are in Minutes; * First Few Occupants; ** Last Few Occupants*

Table 3: Pre-Movement Times as per Different Standards

The calculation of the safe egress times shall be done in 3 methods for the chosen case study:

1. Manual Calculations for RSET, from maximum travel distance and average movement speeds.
2. Software Simulation of egress, without inputting case specific behaviour data.
3. Software Simulation of egress, incorporating occupant profiles and behaviour data from case study.

IV. RESULTS

4.1 Simulations

4.1.1 Simulation 1

The first simulation has been done as a test case for comparison. The default values of software simulation are used in this case. The resultant graph has been plotted of Occupant Vs Safe Egress time has been produced for the test case.

Inputs:

- Population Size: 1180 occupants distributed over 30 floors
- Profiles: Randomized occupant profile with no behaviour inputs
- Movement values as per software default

4.1.2 Simulation 2

The second simulation has been done incorporating the behavioral data from the case study. The resultant graph has been plotted of Occupant Vs Safe Egress time has been produced for the case including behaviour.

Inputs:

- Population Size: 1180 occupants distributed over 30 floors (Constant)
- Profiles: Occupant profile and behaviour inputs as per extrapolation from primary survey
- Movement values as per Secondary case data (Literature).

4.2 Results

Completion Time	Manual Calculation	Sim 1 (Default)	Sim 2
Minimum	1215 (20.26 min) [The max dist. traversed is taken from drawings; avg. is derived from literature; and max time required is calculated]	19 (0.31 min)	136 (2.27 min)
Maximum		1620 (27 min)	2861 (47.41 min)
Average		724 (12.1 min)	1383 (31.35 min)

Table 4: Simulation Results

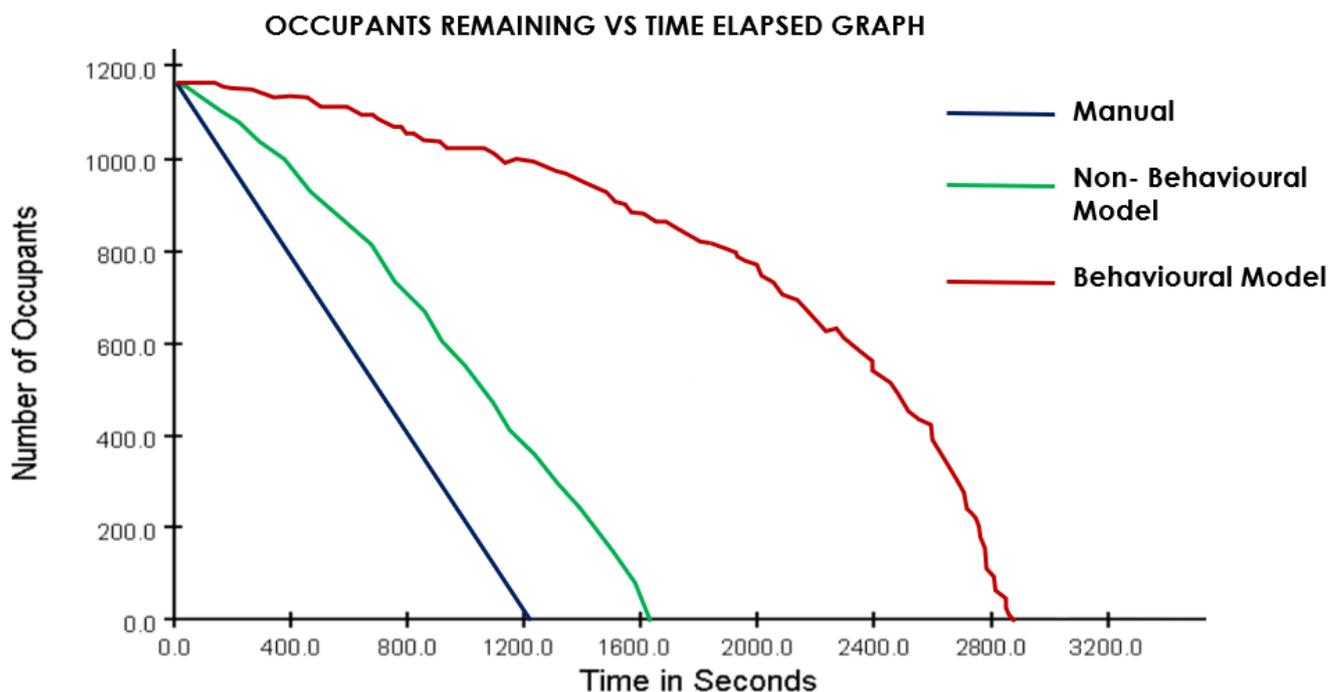


Figure 2: Occupants Remaining Vs Time Elapsed Graph

It is evident from the simulation, that incorporation of behaviour profiles into a evacuation model makes significant difference to the required safe egress time. The average time required has a 91% increase (1.91 times); and the maximum time required shows a 76.6% increase (1.76 times) between the two models. Further, if compared with the manual calculations, the behavioral model has a 135.4% (2.35 times) increase. This value substantiates and validates the initial hypothesis of this seminar, that inclusion of occupant behaviour has a bearing on the safe egress time calculations.

The minimum time required for egress, as per simulation, shows 7.15 times increase between the two models, which is the maximum deviation from the non-behavioral model. This delay is due to the pre-movement activities like perception of cues and decision making by the occupants.

When the graph showing the three calculations is studied, it can be observed that, the line representing the manual calculation has a uniform slope, showing that manual calculations do not take into considerations any speeds variations.

The line representing the non-behavioral model also has a relatively uniform slope, but the slope is lower in this case. It can be thus concluded, that a simulation model without behaviour has a lower slope as it considers a variation in movement speeds due to change in flooring, vertical movement congestion, etc. But it does not incorporate occupant specific variations, i.e., varied speed due to age, unfamiliarity, etc.

Finally, the line representing the behavioral model has different slopes in different time frames. The initial slope is much lower, representing the delays due to lack of alertness, non-perception of alarm or cues, delayed decision making, etc. The slope towards the end increases substantially, representing panic and thus, increases movement speed.

4.3 Validation

It is observed that major delay in evacuation is in the initial phase. Thus, these delays can be directly linked to the occupant behaviour of delayed decision making resulting from unfamiliarity of space. To further validate this, two scenarios were simulated, using the same population size.

- In Case 1: the population has a constant behaviour where all occupants are familiar (they choose the nearest available exit).
- In Case 2: the population has a constant behaviour where all occupants are unfamiliar (they choose the most visible exit).

The range of the two cases is then compared with the original egress time graph to validate this hypothesis.

Completion Time	Heterogeneous	All Familiar	All Unfamiliar
Minimum	136 (2.27 min)	84 (1.4min)	189 (3.15 min)
Maximum	2861 (47.41 min)	2573 (42.88 min)	3985 (66.41 min)
Average	1383 (31.35 min)	1186 (19.7 min)	1937 (32.28 min)

Table 5: Simulation results (Validation)

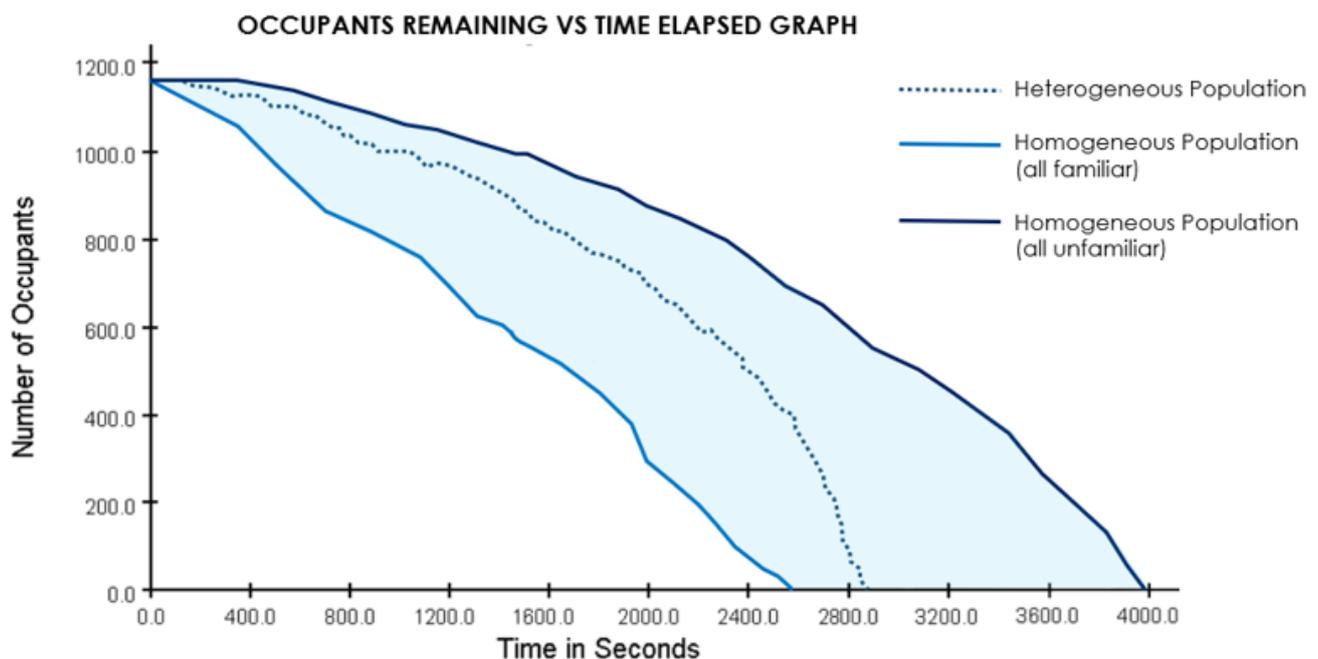


Figure 3: Occupants Remaining Vs Time Elapsed Graph for Validation

V. CONCLUSION

From the study it can be concluded that occupant behaviour causes substantial deviation in the Required Safe Egress time during a fire. It is observed that without occupant behaviour, the slope of the graph between occupants and egress times is uniform. But, when behaviors and occupant profiles are included, the resulting graph has varied slopes at different phases during the egress.

Hence, it can be concluded that the present methodology for calculating egress times using a straight-line graph with uniform slope is incomplete, and occupant behaviour has a bearing on the reliability of the calculation methodology of RSET. The aim of the study is thus achieved.

Also, from the graphs it can be understood that this deviation is maximum in the initial phase of evacuation, meaning that it results primarily from pre-movement delays due to unfamiliarity of space. This observation is further validated using the two homogenous population sets of all familiar, and all unfamiliar occupants. It is seen that if all occupants are familiar to the space, meaning that they use the nearest exits or shortest path for evacuation, then the graph shall have a more uniform slope, and eliminate most of the pre-evacuation delay.

But, in case all occupants are unfamiliar to the shortest evacuation route, the RSET time increases to nearly double of its value (146% increase from initial value of non-behavioural model). It can be thus be concluded that, presence of trained personnel to assist evacuation is necessary for buildings that have been designed using the present methodology.

VI. LIMITATIONS

The study had certain limitations due to time constraints. It has been conducted on a particular type of occupancy only. The hypothesis, though applicable on other typologies, have not been tested in this research, and can be considered a future scope of work for the same. Also, since the conclusions are drawn from a one case study, there is significant room for error in the range of values achieved. Future scope of research in this domain may look at conducting a similar study on more case studies, to increase the sample size, and thus reduce error margins.

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