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Simulating the Effect of Architecture Forming Elements on Resonance Frequency

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Abstract— Forming includes any process that depends on a group of elements that are united by specific organizational relationships that govern relations between each other. Forming aims to specialize the architecture product from others so that it can be linked in the human mind with unique characteristics. The process of architectural formation is a two-way process that is confined between mass and space, depending mainly on the optical properties such as form, size, material, proportion and transparency. The other principle represents the effect caused by the architecture itself through resonance which describes the phenomenon of increased amplitude that occurs when the frequency of a periodically applied force is equal or close to a natural frequency of the building on which it acts [1].

Many simulations software calculates resonance through geometry this research tests the effect of each forming element on resonance frequency using CST Microwave studio. The results show that some elements have an effect on resonant frequency such as form, material, proportion and size. However, doors, windows and orientation have no effect and can be neglected.

Index Terms— architecture forming; resonance; simulation; forming principles.

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1. Introduction

Shape of a building refers to its form. The primary elements of architecture are form and its polar opposite, space. Given the purpose of architecture to provide internal sheltered space for human occupancy, the reciprocal relationship is important [2]. In the design process, both form and space are given shape and size. Another important feature of the shape/space relationship is the positioning of a building form concerning the immediate site and adjacent structures. Exterior space may be defined or incorrectly defined by the building structure; just as internal space is provided by voids in the building form.

Consider the contrast between an infill building that fits closely into its site limits (leaving little unoccupied space on the site apart from perhaps a given outside courtyard) and a freestanding building situated within a wide parking lot. Many singular forms struggle to adequately describe or express a vast area without the assistance of other space-defining forms such as trees, walls, level shifts, and so on. **Form, size, Material, orientation, proportion, and solid & void** are all factors to consider when analyzing or designing an architectural structure [3].

Many studies refer to buildings effect on user's consciousness using EEG recording devices. **Maitreya-Buddha Pyramid – India** [4], **Mosque-Madrasa of Sultan Hassan, St Sergius Church – Egypt** [5] are examples of tested buildings using EEG method. Results show the effect of buildings on user's brain waves which affect consciousness. Changes in brain waves frequency led users to relax, focus and attention. These studies test building effect after construction, but to integrate this effect in design process it must be predicted by simulating resonant frequencies of architectural designs. Identifying the effect of simulated frequencies on brain waves and so consciousness and linking it to building function will improve using efficiency of architecture.

2. Objective

This study tests the effect of each architecture forming element on resonance state in built environment, by using **CST Microwave studio**. The effect of changing in each forming element will be simulated and by comparing results effective and non-effective element can be identified. **The main aim** of this research is to identify which of architecture forming elements can affect resonance state inside building so must be carefully described as a simulation input, or has no effect and can be neglected in order to simplify the simulation process, reduce time and resources. This study fucus on how to simulate and detect the effect of forming elements by computer tool, however Explaining this effect on human behaviour is not in fucus and can take place in further researches.

3. Methodology

In order to achieving research aim, six architecture forming elements -**Form, size, Material, orientation, proportion, and solid & void**- will be tested by changing one element while the other five elements are constant. Changing in outputs (resonant frequency) will make tested element effective. This part consists of six tests, each test has three stages **describe inputs, simulation settings and comparing results**. (Figure 1)

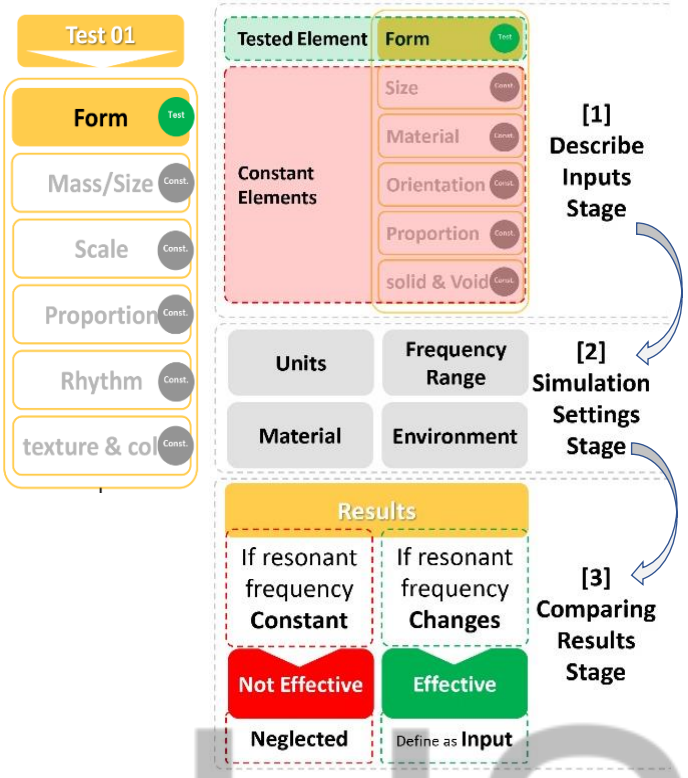


Figure 1: Simulation Methodology

3-1. CST® STUDIO

CST® studio is simulation tool for electromagnetic designing and simulations. Dassault Systèmes the copyright holder for all CST® products is a French software corporation founded in 1981. Accuracy, usability, and speed are the main three pillars of CST® products [6]. CST® builds a three-dimensional model based on ACIS modeling Kernel technology which provides a well-presented graphical environment. Thus, CST® STUDIO SUITE has become widely used by researchers, designers, and engineers working in many fields, including electromagnetic compatibility (EMC), microwaves, RF & optical, static low frequencies EDA, and electronics. One of the main features of CST® studio is the Automated Help, which suggests the most appropriate settings for the simulation created. The program also contains several simulation systems specialized in a wide range of applications [7].

4. Simulation Procedures.

4-1. Test 01 - Form.

To identify form effect three different forms are selected Box, Cylinder and Dome with constant 64m3 volume. All shapes are made of concrete, parallel to X, Y axis and all shapes are hollow with 25cm wall thickness, no doors or windows added. (Figure 2) shows example of inputs in simulation environment.

a. Simulation settings:

Units: Dimensions, m – Frequency, MHZ.
Frequency range: 0-3000 MHZ.
Material: Concrete.
Environment: Open air.

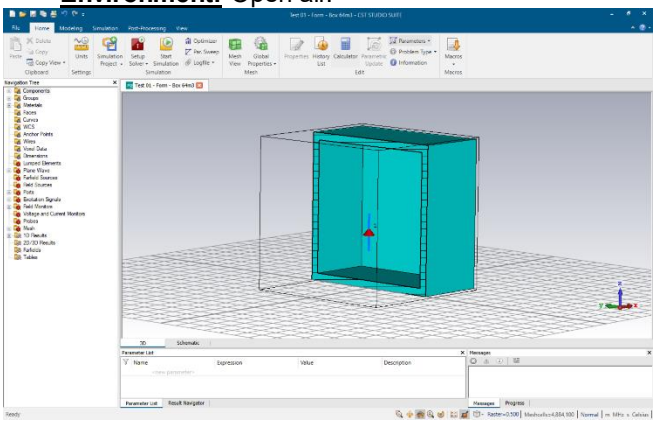
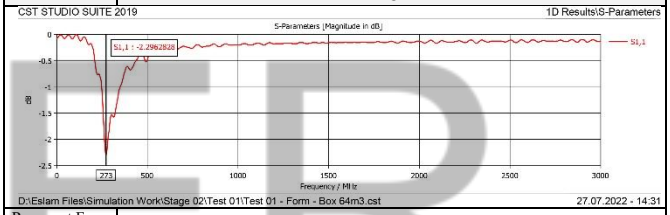
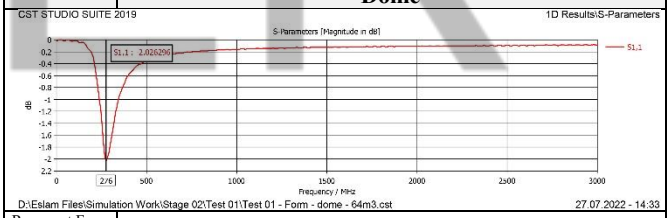
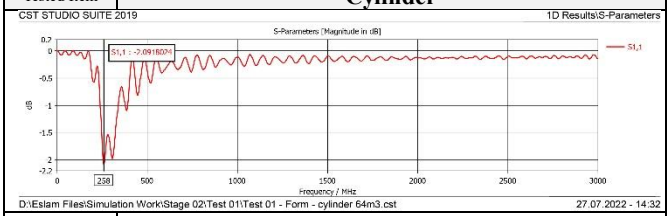


Figure 2: Test 01 – Box - Form Test inputs.

b. Result:

After simulating the three forms resonant frequencies are various for each shape which indicates the effect of changing form on resonant frequency as shown in (table1).

Table 1: Test 01 - Result.

Tested Item	Box
	
Resonant Freq. (MHZ)	273
Tested Item	Dome
	
Resonant Freq. (MHZ)	276
Tested Item	Cylinder
	
Resonant Freq. (MHZ)	258
Effective	

4-2. Test 02 - Size.

To identify the effect of changing in form size two similar boxes are tested, the first has dimensions of 4*4*4m however, the other one is 50% size with 2*2*2m dimensions. The two boxes are made of concrete, parallel to X, Y axis and hollow with 25cm wall thickness, no doors or windows added. (Figure 3) shows example for inputs in simulation environment.

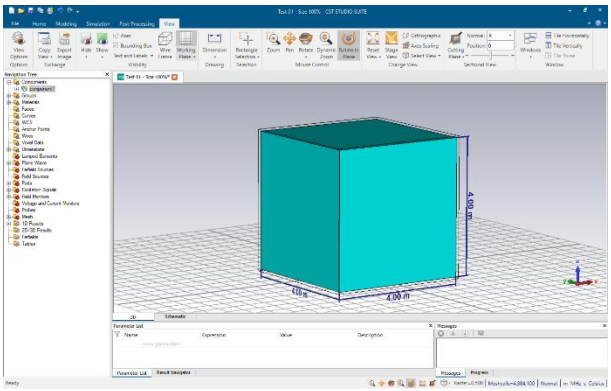


Figure 3: Test 02 – Size Test inputs.

a.Simulation settings:

Units: Dimensions, m – Frequency, MHZ.
Frequency range: 0-3000 MHZ.
Material: Concrete.
Environment: Open air.

b. Result:

After simulating the two boxes resonant frequencies are various for each box which indicates to the effect of changing the form size as shown in (table 02).

Table (02): **Test 02 - Result.**

Tested Item	**Box 4*4*4m**
CST STUDIO SUITE 2019 — 1D Results\S-Parameters\S1,1 — D:\Eslam Files\Simulation Work\Stage 02\Test 02\Test 01 - Size 100%.cst — 27.07.2022 - 14:44	
Resonant Freq. (MHZ)	**273**
Tested Item	**Box 2*2*2m**
CST STUDIO SUITE 2019 — 1D Results\S-Parameters — D:\Eslam Files\Simulation Work\Stage 02\Test 02\Test 01 - Size 50%.cst — 27.07.2022 - 14:51	
Resonant Freq. (MHZ)	**252**
Effective	

4-3. Test 03 - Material.

To identify different material effect one box is modeled with three different materials Concrete, Glass and Wood with constant 64m3 volume. All shapes are parallel to X, Y axis and all shapes are hollow with 25cm wall thickness, no doors or windows added. (Figure 4) shows example for inputs in simulation environment.

a. Simulation settings:

Units: Dimensions, m – Frequency, MHZ.
Frequency range: 0-3000 MHZ.
Material: Concrete/Glass/Wood.
Environment: Open air.

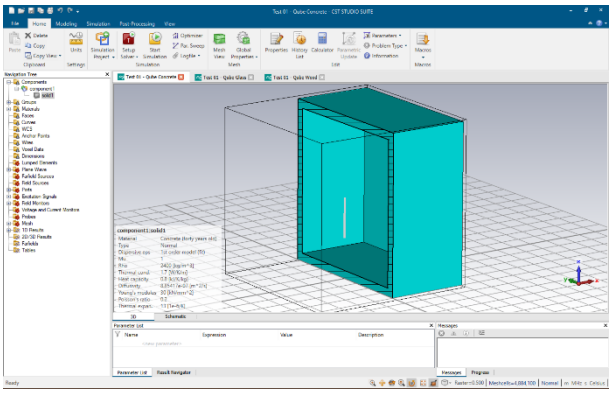


Figure 4: Test 03 – Concrete - Material Test inputs.

b. Result:

After simulating the three boxes with different materials resonant frequencies are various for each material which indicates to the effect of changing material as shown in (table03).

Table (03): Test 03 - Result.

Tested Item	**Concrete**
CST STUDIO SUITE 2019 — 1D Results\S-Parameters — D:\Eslam Files\Simulation Work\Stage 02\Test 03\Test 01 - Qube Concrete.cst — 27.07.2022 - 14:58	
Resonant Freq. (MHZ)	**273**
Tested Item	**Wood**
CST STUDIO SUITE 2019 — 1D Results\S-Parameters — D:\Eslam Files\Simulation Work\Stage 02\Test 03\Test 01 - Qube Wood.cst — 27.07.2022 - 15:12	
Resonant Freq. (MHZ)	**252**
Tested Item	**Glass**
CST STUDIO SUITE 2019 — 1D Results\S-Parameters — D:\Eslam Files\Simulation Work\Stage 02\Test 03\Test 01 - Qube Glass.cst — 27.07.2022 - 15:07	
Resonant Freq. (MHZ)	**291**
Effective	

4-4. Test 04 - Orientation.

To identify the effect of form orientation two similar boxes with constant 64m3 volume are tested, the first is parallel to X, Y axis however, the other one is diagonal with 45 degrees. The two boxes are made of concrete, hollow with 25cm wall thickness and no doors or windows added. (Figure5) shows example for inputs in simulation environment.

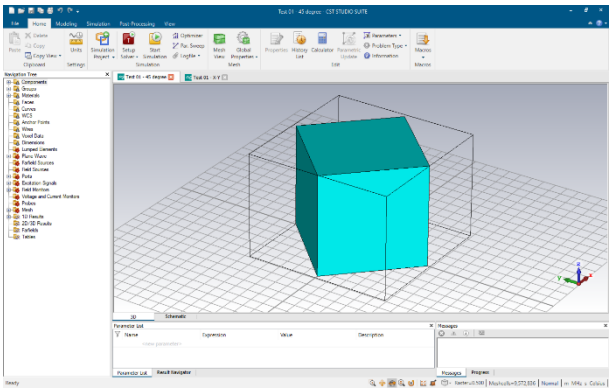


Figure 5: Test 04 – 45 degree - Orientation Test inputs.

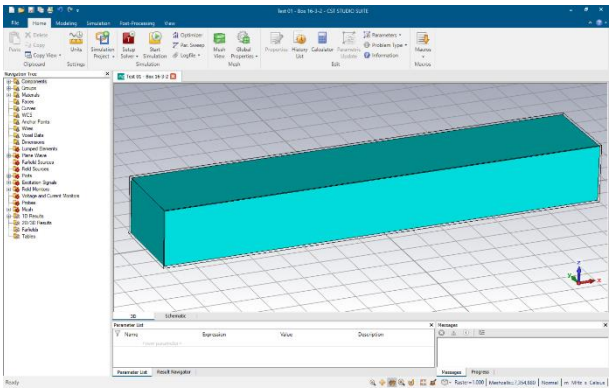


Figure 6: Test 05 – 16:3:2 - Proportion Test inputs.

a. Simulation settings:

Units: Dimensions, m – Frequency, MHZ.
Frequency range: 0-3000 MHZ.
Material: Concrete.
Environment: Open air.

b. Result:

After simulating the two boxes resonant frequencies are the same for each box which indicates to orientation has no effect as shown in (table 04).

Table (04): Test 04 - Result.

Tested Item	**Box Parallel to X, Y Axis**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters S-Parameters [Magnitude in dB] D:\Eslam Files\Simulation Work\Stage 02\Test 04\Test 01 - X-Y.cst 27.07.2022 - 15:17	
Resonant Freq. (MHZ)	**273**
Tested Item	**Diagonal Box 45 Deg.**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters S-Parameters [Magnitude in dB] D:\Eslam Files\Simulation Work\Stage 02\Test 04\Test 01 - 45 degree.cst 27.07.2022 - 15:25	
Resonant Freq. (MHZ)	**273**
Not Effective	

4-5. Test 05 - Proportion.

To identify the effect of changing shape proportions, cubic shapes are modeled with three different dimensions (4*4*4m cube – 8*6*4m cuboid – 16*3*2m cuboid). All shapes are parallel to X, Y axis and all shapes are hollow with 25cm wall thickness, no doors or windows added. (Figure 6) shows example for inputs in simulation environment.

a. Simulation settings:

Units: Dimensions, m – Frequency, MHZ.
Frequency range: 0-3000 MHZ.
Material: Concrete.
Environment: Open air.

b. Result:

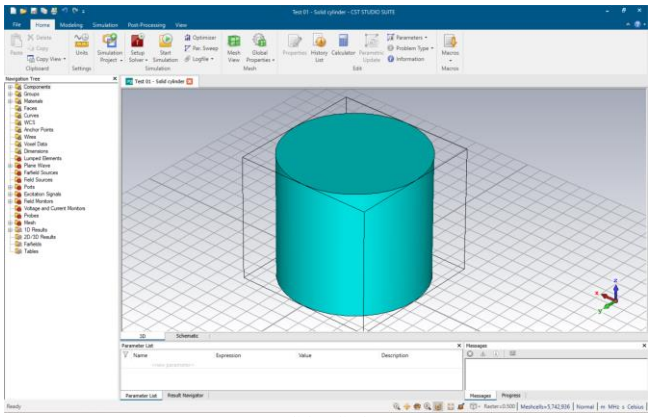
After simulating the three cuboids with different dimensions resonant frequencies are various for each shape which indicates to the effect of changing proportion as shown in (table 05).

Table (05): **Test 05 - Result.**

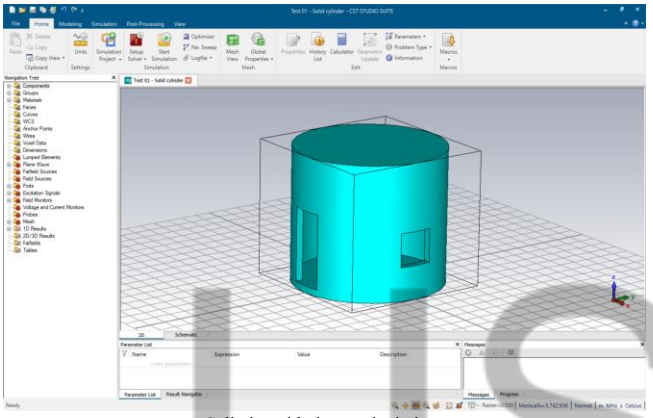
Tested Item	**Box 4*4*4 m**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters S-Parameters [Magnitude in dB] D:\Eslam Files\Simulation Work\Stage 02\Test 05\Test 01 - Box 4-4-4.cst 27.07.2022 - 15:31	
Resonant Freq. (MHZ)	**273**
Tested Item	**Box 16*3*2 m**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters S-Parameters [Magnitude in dB] D:\Eslam Files\Simulation Work\Stage 02\Test 05\Test 01 - Box 16-3-2.cst 27.07.2022 - 16:27	
Resonant Freq. (MHZ)	**267**
Tested Item	**Box 8*6*4 m**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters S-Parameters [Magnitude in dB] D:\Eslam Files\Simulation Work\Stage 02\Test 05\Test 01 - Box 8-6-4.cst 27.07.2022 - 15:46	
Resonant Freq. (MHZ)	**282**
Effective	

4-6. Test 06 – Solid & Void.

To identify the effect of windows and doors two different forms are selected Box and Cylinder with constant 64m3 volume. shapes are tested tow times, first without any slots and the other a door and a window will be added. All shapes are made of concrete, parallel to X, Y axis and all shapes are hollow with 25cm wall thickness (Figure 7).



Solid Cylinder.



Cylinder with door and window.

Figure 7: Test 06 – cylinder - Solid & Void Test inputs.

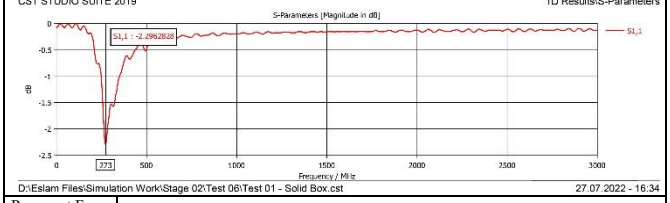
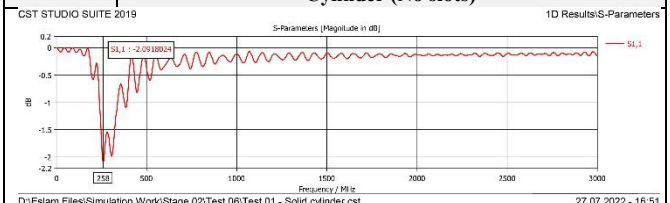
a.Simulation settings:

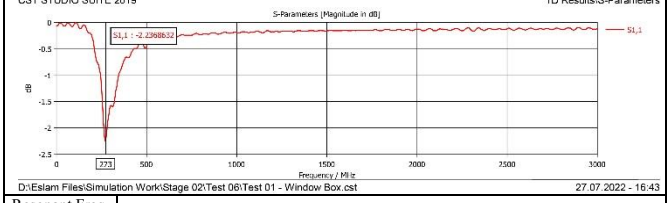
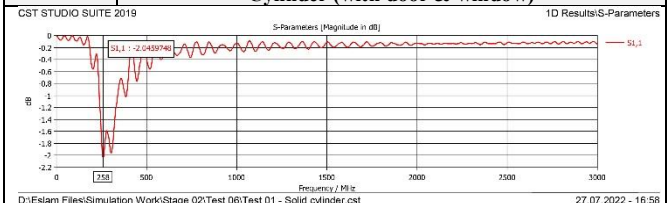
Units: Dimensions, m – Frequency, MHZ.
Frequency range: 0-3000 MHZ.
Material: Concrete.
Environment: Open air.

b. Result:

After simulating the four forms resonant frequencies are the same for each shape which indicates that there is no effect of building doors and windows on resonant frequency (table 06).

Table (06): **Test 06 - Result.**

Tested Item	**Box (No slots)**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters	
D:\Eslam Files\Simulation Work\Stage 02\Test 06\Test 01 - Solid Box.cst	27.07.2022 - 16:34
Resonant Freq. (MHZ)	**273**
Tested Item	**Cylinder (No slots)**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters	
D:\Eslam Files\Simulation Work\Stage 02\Test 06\Test 01 - Solid cylinder.cst	27.07.2022 - 16:51
Resonant Freq. (MHZ)	**258**

Tested Item	**Box (with door & window)**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters	
D:\Eslam Files\Simulation Work\Stage 02\Test 06\Test 01 - Window Box.cst	27.07.2022 - 16:43
Resonant Freq. (MHZ)	**273**
Tested Item	**Cylinder (with door & window)**
CST STUDIO SUITE 2019 / 1D Results\S-Parameters	
D:\Eslam Files\Simulation Work\Stage 02\Test 06\Test 01 - Solid cylinder.cst	27.07.2022 - 16:58
Resonant Freq. (MHZ)	**258**
Not Effective	

5.RESULTS.

After simulating all six tests, results show that resonant frequency effected by elements like form, materials, dimensions of building and ratio can affect simulation results. On the other hand, orientation and openings (Doors and Windows) have no effect on simulation outputs. All results are summarized in (table 07).

Table (07): **Result Summery.**

Test No.	Test Result (MHZ)				Decision
Test 01 **Form**	**Box** 273	**Dome** 276	**Cylinder** 258		**Effective**
Test 02 **Size**	**Box -**100% 273	**Box-** 50% 252			**Effective**
Test 03 **Material**	**Concrete** 273	**Wood** 252	**Glass** 291		**Effective**
Test 04 **Orientation**	**Box** X, Y Axis 273	**Box** Diagonal 273			**Not Effective**
Test 05 **proportion**	**B.** 4*4*4 273	**B.** 16*3*2 267	**B.** 8*6*4 282		**Effective**
Test 06 **Solid & void**	**Box** No slots 273	**BOX** Win & door 273	**Cylinder** No slots 258	**Cylinder** Win & door 258	**Not Effective**

6.DISCUSSION.

In test 01, changing form geometry causes different resonance frequencies when other elements were constant. So, building form must be modelled as it is in simulation environment as one of the effective elements.

In test 02, changing model size with 50% causes different resonance frequencies when other elements were constant. So, building must be modelled with its real dimensions in

simulation environment as one of the effective elements.

In test 03, simulating different materials for the same model causes different resonance frequencies when other elements were constant. So, building must be modelled with its actual materials in simulation environment as effective element.

In test 04, changing model orientation from X, Y Axis to diagonal causes the same resonance frequencies when other elements were constant. So, building Orientation can be neglected in simulation environment inputs as one of non-effective elements.

In test 05, changing the ratio between model length, width and Height changes geometry type and causes different resonance frequencies when other elements were constant. So, building proportion must be modelled with its actual ratio in simulation environment as one of the effective elements.

In test 06, modelling slots (doors & windows) to a blank geometry causes the same resonance frequencies with no change when other elements were constant. So, building doors and windows can be neglected and not modelled in simulation environment as non-effective element.

7.CONCLUSION.

Simulation is used in many fields, such as performance tuning or optimizing, testing, safety engineering and training. it's also used when the real systems can't be utilized, or during design process when it's not yet built. Simulation process requires use of models which represent the key characteristics or behaviors of a system or process. Often, computers are used to execute simulation, the main issue is to simplify information and procedures required to create models, in order to save time, effort and the need for high performance computers.

This research tests six elements used in architecture forming process, to simplify architecture model creation testing results refers to **four effective elements (form, size/volume, material, proportion)** which information is required to be fully entered into simulation environment. The other **two elements (orientation, solid & void) have no effect** in simulation outputs and can be neglected during model creation process.

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