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Shape Grammar and Formal Aesthetic Functions Spatial Relationship for Car Chassis Design

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Abstract
The developing of computer tools accelerate the designs phase for designers but the aesthetics of product appearance cannot be neglected. Shape grammar is a general computational language that manipulates shapes to generate designs. By defining the spatial relationships between those forms and how the forms are related to each other, shape rules can be written. Shape grammar was used as a tool for observing spatial relationships of design elements and principles of a space frame chassis and using biomimicry theory to give inspiration and ideas to create the new concept of supercars chassis design.

Keywords: biomimicry; car chassis;; formal aesthetic functions and shape grammar.

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1.0 Introduction

A chassis is a physical edge or structure of a vehicle, a plane, a personal computer, or some other multi-segment gadget. It is the fundamental supporting structure of a vehicle to which every single other part are joined, and it tends to be similar to the skeleton of a living being. The segments of the vehicle like transmission framework, axles, wheels, tires, suspension, controlling framework like braking, directing, and so forth., and even electrical frameworks are mounted on the case outline. Case is the primary mounting for every one of the parts including the body. Along these lines, it is likewise called as the 'Conveying unit' and the Backbone of a vehicle. Until 1930's, virtually every vehicle had a structural frame, separate from the cars body. This construction design is known as "body- on- frame".

Since then, nearly all passenger cars have received Uni-body construction, meaning their chassis and bodywork has been integrated into one another. The last United Kingdom mass-produced car with separate chassis was *Triumph Herald*, which was discontinued in 1971. However, nearly all trucks, busses, and pickups, continue to use a separate frame as their chassis.

In this case only focus some critical issue that faced by cars user that can impact them when accidents. According to the article New Straits Times published on (February11,2018).Chassis plays an important role in the manufacturing of the automotive industry. The chassis used should have strong resilience in reducing the impact of injuries on users during the accident. To increase crash performance in automotive vehicles it is necessary to use new techniques such as use of energy absorber and materials.

Components linked to crash safety should transmit or absorb energy. The energy absorbing capability of a specific component is a combination of geometry and material properties. (Andersson R, Schedin E, Magnusson C, Ocklund J,2002). Based on this issue, there have several problem that be found. The low safety in car chassis during car crash in one of the problem for this issue. New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) have do the car crash test and giving a rating based on the test.

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Based on the test some cars have a critical damage and semi critical damage at some part. This is because existing chassis less stiffness because of the structure and material. Beside existing chassis not help to reduce the car mess that can impact movement during crash.

Compact car segment is the get the worst result during car crash test this because the cars have short crumple zone. To short crumple zone might drag the force toward passenger. The percentage of users with severe injuries is high. According the car crash test, existing car chassis have low body torsional stress is the factor of bending or rupture of frame. Moreover existing car chassis have a lack of support structure or beam to react up collision.

Chassis is very important part for automotive industry. New concept car chassis must have high torsional strength frame pillar and roof pillar. For example increasing thickness of the frame, create more geometrical shape, which acts as a force distribution or high tensile material usage. New concept car chassis can make improvement at crumple zone. Long crumple zone can decrease drag the force to passengers compared with short crumple zone. High durability chassis floor are needs which will support the entire chassis and support passenger door frame

1.1 Research problem

This research starts with the existing car crash test based on several portal. This research also studies on several brands that produced compact car segment in Asian country. Car crash test ratings are giving based on the frontal crash, frontal overlap crash, rollover crash and side crash. The compact car frontal crash test rating from ANCAP, ASEAN NCAP and EUROCAP; based on the rating, Perodua get the low rating in frontal crash. From 6 Perodua cars are tested, all the cars get the low result with rating 2/5. Toyota, Nissan, Mitsubishi, Kia and Hyundai get moderate result from the test and all the car are test get a rating 3/5 and 4/5. One of Mazda brand and one car from Honda have the excellent rating level that which is 5/5 from the frontal crash test. Honda Accord and Mazda 3 get the full rating from the test.

The compact car side crash test rating from ANCAP, ASEAN NCAP and EUROCAP; based on the rating, 2 cars from Suzuki, 2 cars from the Toyota, 3 cars from Nissan, 2 cars from Mitsubishi, 1 car from Mazda, and 1 car from Honda get moderate level with 3/5 and 4/5 rating based on the side crash test. Subaru, Kia and Hyundai get the excellent level rating as the brand get full rating 5/5.

The compact car rollover crash test rating from ANCAP, ASEA N NCAP and EUROCAP; based on the rating, some Perodua car and Proton brand get a low rating of rating 2/5. Toyata, Mitsubishi and Subaru are moderate level rating as the car tested get the 3/5 and 4/5 rating. Hyundai, Mazda, and Honda have a excellent rating from the rollover crash test rating by getting full rating 5/5.

The compact car crash test rating from ANCAP, ASEA N NCAP and EUROCAP; based on the rating, all Perodua car gets low rating with 2/5. Mitsubhishi and Hyundai is a moderate level because all the cars tested get 3/5 and 4/5 rating. Based on the test Subaru has excellent level rating because most of the cars tested get 5/5 rating. Based on the data, we can identify certain problem related to the frontal crash, frontal overlap crash, side crash and rollover crash test. For the frontal and frontal overlap crash test Perodua get the low rating because most of short crumple zone, low torsional strength frame pillar and low durability chassis for beam are also problem when having crash from side impact**.** For the rollover crash test Produa get a low rating because of the low torsional strength roof pillar.

It is clear that the smaller the car, the lighter the car, the mass the greater danger it is during crashes. However if the stiffness of the car structure well designed, therefore it will minimize the danger of the car in crashes. There were numerous studies being done in engineering related to car mass, stiffness and geometrical incompatibility and also over aching topic of form follow function in the field of engineering, architecture and design. However, in design areas, there are lacks of study being done to complement the translation of form in generating car structure in relation to super car design. The above mentioned serve a gap in this research and it provides a platform as it tries to give aesthetics as function.

1.2 Research objectives

The aim for this research to explore the supercar structure design by adapting the principal of form follows function using shape grammar as a tool in generating chassis design

The objectives of this research are:

1. To analyze the association of the subject matter spatial and formal aesthetic functions related to strength.
2. To translate the findings of the subject matter spatial and formal aesthetic functions related to strength for the construction of the supercar structure.

2.0 Literature review

2.1 Biomimicry

Biomimicry is an applied science that as the motivation for the arrangement toward human issue through the investigation of characteristic plans, framework and procedures. By study all the more profoundly into how nature tackles issues that are experience today, time arrangements could be separated and new bearing for our constructed condition could be investigate. Biomimicry additionally based on

nature and the whole biological system which are emulated as a reason for a plan in the field of engineering and architecture. This has due to turn into a rousing wellspring of conceivable new development and potential ideas to make progressively maintainable and regenerative condition.This term has appeared since 1982 and it was popularized by a scientist and the author who called JainedBenyus 1997. Architects and designer have sought science for motivation and they have looked for not simply to emulate the types of plants and creatures, however, to discover techniques and structure practically equivalent to the procedure of development and advancement in nature.

As state by Pawlyn (2011), the term biomimicry show up since 1962 in logical researcher and developed in utilization especially among materials researcher in 1980s. Some researcher favored the term was "biomemetic" or less as often as possible, "bionics". Educator of Biomemetics Julian Vincent characterizes it as "the reflection of good structure from nature" and the organic science essayist characterize it as "the cognizant imitating of nature's virtuoso". The fundamental basic qualification among 'biomimetics' and 'biomimicry' is that various users of the last mean it to be expressly revolved around making sensible plans, where as the past can be, and on occasions has been, applied to fields of attempt, for instance, military development.

2.2 Type Of Chassis

2.2.1 Space Frame:

It is otherwise called 3-Dimentional body outline. It is called so on the grounds that dissimilar to different case types which are basically 2-dimensional having just length and expansiveness in this structure the third measurement has been considered. By considering the profundity of the casing 3-D Frames have figured out how to expand the twisting quality and solidness of the whole plan.These kinds of edges have been for the most part utilized for pro autos, for example, sports dashing vehicles. A portion of the remarkable models for space outline vehicles incorporate Audi R8, Ferrari 360, Lamborghini Gallardo, Mercedes-Benz SLS AMD and Pontaic Fiero.This sort of vehicle configuration can be mostly utilized for low volume creation. One significant part of this vehicle structure is that every one of the planes of the edge ought to be completely triangulated with the goal that all components are basically stacked in strain or pressure. The fundamental disadvantage of this plan is that it encases a significant part of the working volume of the vehicle and it can make access for both the driver and the motor trouble, hence the Space edges have been structured with removable segment joined by stick joints. Such a structure can be seen around the motor of the Lotus Mark III. In spite of the fact that the space casing configuration is considered to some degree badly designed for it travelers, the fundamental preferred position of this plan is the absence of twisting powers in the cylinders that enable it to be displayed as a stick jointed structure implying that the removable segments need not be intended to decrease the quality of the amassed casing. . (Julian Happian-Smith, 2012)

2.2.2 Sub Frame:

The main advantage of this chassis is that it is stronger and lighter than the conventional monocoque design without increase of production cost. And the main drawback of this chassis is that it is still not strong or light enough for the sports cars. These sub casings are usually found at the front or backside of vehicles and are utilized to connect the suspension to the vehicles. It might likewise contain the motor and transmission and it's ordinarily a cylindrical or box sheet development. A portion of the instances of traveler vehicles utilizing such a development are the 1967-81 GMF Platform and the GMX Platform 1962.

2.2.3 Ladder Frame.

The Ladder Frame is one of the least complex and most seasoned all things considered. It comprises of two symmetrical pillars, rails, or channels running the length of the vehicle. The stepping stool edge is called so in light of the fact that it takes after a stepping stool with two side rails and a few cross pillars. The stepping stool outline suspension is developed with cross light emissions segments just as side edges; this as a result of the torsional firmness to the entire structure is low (Mulley, 2015)The torsion in the cross individuals is responded as bowing in the side casings, and the twisting in the cross individuals, responded as torsion in the side edges. It is additionally seen that every one of the individuals are stacked in torsion and because of their low torsional constants. This edge has low torsional firmness. The significant point is to see that on the off chance that the open segments are supplanted by shut areas, at that point the torsional firmness is incredibly expanded. This can be seen in the vehicles, for example, Land Rover. The best preferred position of the stepping stool casing is its flexibility to oblige different vehicle body shapes. It is especially utilized for light business vehicles. It is still broadly utilized for box vans and tankers to separable compartments. (Julian Happian-Smith, 2012)

2.2.4 Backbone tube Chassis:

The spine cylinder configuration is all around usually found in games autos. It comprises of a solid rounded spine which is normally rectangular in cross-area that interfaces the front and back suspension connections of the vehicle. This plan was first created in 1923 by Hans Ledwinka who was the boss planned at Tatra overwhelming trucks. He further upgraded this plan with 6*4 model Tatra 26, which had extraordinary rough terrain capacities. A portion of the vehicles which are utilizing this case configuration are Europa, Lotus E soul and Skoda, and so forth. A few vehicles likewise utilize the spine some portion of the case to fortify is, for example, Volkswagen Beetle. Subsequently, the idea of cross breed spine stepping stool frame created. On this respect, the Locost was created by utilizing this idea of a spine notwithstanding the external space frame.

Some of the notable merits of this chassis design are as follows:

- It has a standard super structure that can withstand torsion twist and subsequent wear that can reduce the vehicle’s lifespan.

- The half axles will have better contact with ground when they are operated off-road, when compared if they are operated on roads.
- A thick tube covers the most vulnerable parts of the drive shaft so that the whole system would be highly reliable. Even here the problem related to their repairs might occur which could be complicated.
- The modular system which exists in the design enables a configuration different axle vehicle with different wheel bases.
- Adding to this demerit that backbone chassis is having for a given torsional stiffness when with compare Uni-body.
- This Design has a major drawback when it comes to the aspect of safety as the chassis gives no protection again side impact such as collisions.

2.2.5 X- Frame or Cruciform Frame:

General Motors utilized the X-Frame plan, during the late 1950's and mid 1960's. In which the rails from close by the motor seamed to cross the traveler compartment, each containing to the furthest edge of the cross bar at the outrageous back of a vehicle.

This structure was especially picked to diminish the general load of the vehicle paying little heed to the addition in the size of the transmission and propeller shafts bumps, since can column had sought shelter the edge rails. It is likewise seen that few models have differential found not by the standard bar among hub and casing however by a swiveling appendage on the differential associated with an attachment in a wishbone relied on to a cross-individual from the edge. The significant disadvantage of this plan is that it needs side rails in this way it neglects to give satisfactory side effect and crash security. In this manner, this plan likewise flops on the part of structure well being. Accordingly, the border edge has supplanted this X-outline. (Julian Happian-Smith, 2012)

2.2.6 Perimeter Frame :

The border casing attempts to beat the downsides of the x-outline plan. It is mostly utilized in cruisers, having various shapes and sizes. The explanation behind this is most cruisers have a twisted adaptation of this cylindrical casing structure. The fundamental point of this plan is to make the briefest way between the most focused on parts of the cruiser, for greatest firmness and steadiness. In his plan, the front forks are mounted at the furthest left end and the back swing arm is connected to the furthest right. The motor is set in the unfilled space between them. The border edge can be believed to be utilized in Bajaj Pulsar 200 Ns motorbike. The motor is suspended in the center with the wire outline around it. The chamber head additionally applies weight on the edge therefore expanding and amplifying the firmness of the casing, as the heaviness of the edge casing is low. It helps in mass centralization henceforth improving the taking care of qualities of a vehicle. (Pratik Patole, 2015).

3.0 Methods

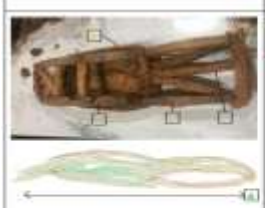
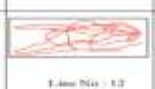
3.1 Sampling

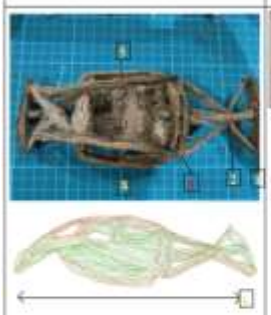
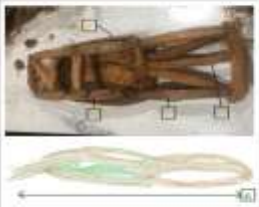
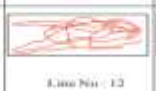
Coconut husk and the supercar space frame were chosen as a sampling to create a new concept of chassis design

3.2 Data collection process

Several of coconut husk model were developed and analyzed to evaluate the spatial relationship and formal aesthetic functions in order to get a good strength of structure and aesthetic as in Table 1

Table 1. An analysis of coconut husk model

Coconut Husk	Line No :	Texture No :	Art Elements	Principle of Design	Pro and Con
	 Line No : 7	 Texture No : 7	1. Have a thick straight angular and flowing line 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines 4. Overlapping Space	1. This wire structure are asymmetrically 2. The wire structure create a movement on the structure	**Stiffness :** 1. Low bending on frontal structure. 2. Good bending on frontal 3. Low stiffness on frontal overlap structure. 4. Low bending on roof pillar 5. High stiffness on side structure **Torsional :** 6. Good torsional during twist test except frontal structure. **Improvement :** 1. Identify and reconstruct again on frontal structure. 2. Increase thickness on roof pillar 3. Refine the structure to get high torsional on total structure.
	 Line No : 13	 Texture No : 13	1. Thin,angular horizontal and broken line 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. This wire structure are asymmetrically 2. The wire structure create a movement on the structure	**Stiffness :** 1. Good stiffness on frontal structure. 2. Good bending on frontal overlap 3. Good bending on roof pillar 4. Good stiffness on side structure **Torsional :** 5. High torsional during twist test **Improvement :** 1. Find the good form that can help more stiffness on chassis structure

Coconut Husk	Line No :	Texture No :	Art Elements	Principle of Design	Pro and Con
	 Line No : 7	 Texture No : 9	1. Have a thick,straight angular and flowing line. 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. Unity and Variety 2. Have a symmetry line 3. The variety of line make the form looks rhythm and movement	**Stiffness :** 1. Good bending in frontal. 2. Good stiffness on frontal structure 3. Low stiffness on frontal overlap 4. Good bending on side structure 5. Good bending on roof pillar. **Torsional :** 6. Good torsional at certain part and lack on frontal and rear torsional. Improvement : 1. More thickness bending on frontal. 2. Refine the structure that can maintain the frontal structure stiffness. 3. Fine the structure than can help to support the frontal and frontal overlap structure. 4. Maintain the stiffness and thickness on side structure 5. Refine the thickness to get more better to maintain the bending of roof pillar. 6. Identify the structure in certain part more focus on frontal and rear to get the highly torsional when twist test.
Coconut Husk	Line No :	Texture No :	Art Elements	Principle of Design	Pro and Con
	 Line No : 7	 Texture No : 7	1. Have a thick,straight angular and flowing line. 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. This wire structure are asymmetrically 2. The wire structure create a movement on the structure	**Stiffness :** 1. Low bending on frontal structure. 2. Good bending on frontal 3. Low stiffness on frontal overlap structure. 4. Low bending on roof pillar 5. High stiffness on side structure **Torsional :** 6. Good torsional during twist test except frontal structure. **Improvement :** 1. Identify and reconstruct again on frontal structure. 2. Increase thickness on roof pillar 3. Refine the structure to get high torsional on total structure.
	 Line No : 12	 Texture No : 11	1. Thin,angular horizontal and broken line 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. This wire structure are asymmetrically 2. The wire structure create a movement on the structure	**Stiffness :** 1. Good stiffness on frontal structure. 2. Good bending on frontal overlap 3. Good bending on roof pillar 4. Good stiffness on side structure **Torsional :** 5. High torsional during twist test. **Improvement :** 1. Find the good form that can help more stiffness on chassis structure
Coconut Husk	Line No :	Texture No :	Art Elements	Principle of Design	Pro and Con
	 Line No : 13	 Texture No : 12	1. Have a thick,straight angular and flowing line. 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. Unity and Variety 2. Have a symmetry line 3. The variety of line make the form looks rhythm and movement	**Stiffness :** 1. Good stiffness on body structure. 2. Good bending on frontal,roof pillar and sides 3. Continuity design flow from frontal to rear chassis. 4. Design flow help structure bending on frontal overlap 5. Aerodynamic shape **Torsional :** 6. High torsional when twist. **Improvement :** 1. Make more form look more aerodynamic. 2. Make form more radical design 3. Improve the continuity of shape from the frontal to the rear to support help give more high torsional for the chassis.

Coconut Husk	Line No :	Texture No :	Art Elements	Principle of Design	Pro and Con
	 Line No : 13	 Texture No : 12	1. Have a thick,straight angular and flowing line. 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. Unity and Variety 2. Have a symmetry line 3. The variety of line make the form looks rhythm and movement	**Stiffness :** 1. Good stiffness on body structure. 2. Good bending on frontal,roof pillar and sides 3. Continuity design flow from frontal to rear chassis. 4. Design flow help structure bending on frontal overlap 5. Aerodynamic shape **Torsional :** 6. High torsional when twist. **Improvement :** 1. Make more form look more aerodynamic. 2. Make form more radical design 3. Improve the continuity of shape from the frontal to the rear to support help give more high torsional for the chassis.

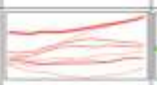
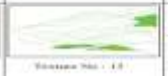
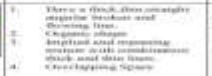
Coconut Husk	Line No :	Texture No :	Art Elements	Principle of Design	Pro and Con
	 Line No : 3	 Texture No : 4	1. Thick,thin and horizontal line 2. Organic shape 3. Implied and repeating texture with combination thick and thin lines. 4. Overlapping Space	1. Unity and Variety 2. Have a symmetry line 3. The variety of line make the form looks rhythm and movement	**Stiffness :** 1. Good stiffness on frontal structure 2. Good bending roof pillar structure 3. Good stiffness on side structure **Torsional :** 4. low torsional when twist roof 5. To geometrical shape 6. Form not really aerodynamic. 7. Form not continuity line to support to entire chassis structure. **Improvement :** 1. Upgrade the form to more continuity to support the entire chassis. 2. Create form looks more aerodynamic to help spread the force during crash
	 Line No : 4	 Texture No : 10	1. Thick,thin, angular,flowing and horizontal line 2. Organic shape 3. Have a implied and repeating,texture with rough and soft line 4. Overlapping space	1. This wire structure are symmetric 2. The wire structure create a movement on the structure 3. Have a emphasis elements on the solid green part	**Stiffness :** 1. Good stiffness on frontal structure 2. Good bending roof pillar structure 3. Good stiffness on side structure 4. The form create more stiffness on frontal structure 5. The form also help good bending on roof pillar and side 6. Form looks more aerodynamic shape. 7. Continuity line base on the form 8. The form not support from frontal to the rear structure. **Torsional :** 9. low torsional when twist Improvement : 1. Upgrade the form to make chassis high torsional. 2. Identify the form again to make the whole chassis more stiffness
					
					

Fig.1: The development of coconut husk model

4.0 Findings

Based on the analysis, it was found that, that the last or the coconut husk model number 10 is the best structure .Overall structure in a good level. Good stiffness on frontal structure, frontal overlaps structure, roof structure and side structure. Moreover this structure designs in good bending on frontal, roof pillar and sides. The continuity design flows from frontal to rear chassis make this structure more strength. Furthermore, this structure has a high torsional when twist. Related with the study about the crash worthiness, this structure can help to protect the passenger during crash because have a good torsional. This structure also look aerodynamic shape that can help to reduce the co-efficient drag and suitable for supercars to be aerodynamic. The model was further developed to corporate the aesthetic of the chassis design as in Figure 1.

5.0 Discussion

Using a shape grammar is a good approach to morph a spatial relation between a subject matter as in this study is the coconut husk and also the formal aesthetic functions. There were interesting shapes can be found that help to generate ideas related to combining the theory of chassis design from engineering field and also the field of art. However, using coconut husks to construct a model is very challenging as it contains massive of fibres but the result was interesting when morphing using shape grammar.

6.0 Conclusion & Recommendations

It can be concluded that using a coconut husk models as to simulate the crashworthiness by using torsional as to also evaluate the aesthetic structural shapes is beneficial for design students as to understand the principal of chassis design related to formal aesthetic functions as to get a functional aesthetic chassis design. Using this approach it helps to generate and explore more ideas related to chassis design. It is recommended that to also explore the model using coconut coir fiber, cocopeat, cocopeat brick, cocosheet, coconut fiber-cement board (CFCB) or coconut fiber board (CFB). It is also recommended to abduct shape grammar approach as a tool to analyze the formal aesthetic functions as to get rich data on shapes.

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