Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

# The Design Foundations of the Light Metal Structures Between Mathematical Laws and Aesthetic Values

Prof. Mohammad Abdullah Almandrawy*
*Metal Furniture and Construction (Architecture Design),
Architecture and Design College,
Jazan University, KSA

Assistant Prof. Eman Sayed Badawy Ahmed **
**Textile Engineering (Textile Printing,
Dyeing and Finishing),
Architecture and Design College,
Jazan University, KSA

***Abstract*:- Light metals structural get defined through its elements, that organization of space and rhythm that relates to design. According to an expected loads path of a structural system provides for a common language for designers and structural engineers during the design. Problem: One of the prevalent issues facing the methodology of teaching studio design of the light metal structure is the balance between designing think and mathematic think, With confirmation, the goal of the designer in these steps focuses more on the aesthetics, or ''form'' of a structure. While the Aim of this research is the design aspects of focus on stability and efficiency, or its function, understanding the structural laws of a light metal which allows altering the form of the model through structurally sound rules. Designers need to appreciate the impact of loading on beams, columns, and trusses. They should understand the differences between compression and tension members so that they can use this information. Therefore, the research reached design standards based on the simplification of structural concepts and useing in the architectural design foundations with using athletic aspects.**

***Key words: Metal - Structural -Design – Mathematic.***

## 1- INTRODUCTION

Design is a creative activity involving imagination, intuition and deliberate choice, it is exactly what should a student understand. Design of light metal structures has always been inventive and adaptable. Our current era however, is unique in its technological potential combined with societal and environmental challenges. [(1)]

The students need to better understand the interdependency between the structures that they design and their impact on design. In many circumstances design used student's elements of nature, design principles come up with their design concept.contact to design light metal structural and structure class should capitalize on this by analyzing the structural concepts of natural elements. [(2)]

Another method also of teaching design is like to flip through magazines or search the internet for sophisticated looking buildings forms without understanding the building systems. Language understanding for design light metal structural an important part in design metal structural education, as it requires a minimum of required design knowledge to show how a metal structure functions. In the new language, the traditional diagrams of deformation, internal forces and stresses that designs normally use to express structural function and behavior are reduced to a few symbols that mainly express the essence of a structure's logic.

The lack of understanding on the relationship between various engineering performance requirements (e.g. mechanical properties, thermal properties, etc.) and the structure design often prevents efficient design of light metals structurals for functional purposes. When going back in history to a remarkable example which demonstrates the concept of the design of aesthetics and also explains some fundamental knowledge. [(3)]

Most students seem to relate easily to structural order as an understanding of the structural logic of transferring loads to the supports, while the characteristics of structural dimensions appeal a tactile, experiential understanding of structures. The students educated with antiquated methods that were best suited to simple light assuming that designers have a more dominant "artistic brain" and designs have a more dominant "logical brain", then the characterization of the type of structural material must start by arousing the side of the brain that is most comfortable with the material and then venture into the less active territory.[(4)]

The structural shape is both quantitative and qualitative in nature. Its quantitative dimension regulates the order and construction of design forms. Its qualitative nature sets the proportions of design forms and represents an expression of the order of the universe as a visual representation of the truth. Each figure or geometric shape, when seen from the perspective of its symbolic meaning, represents an echo of unity and a reflection of the values and principles within the larger frame beyond that unity (universal unity).

Arguably what characterises late twentieth century and early twenty first century technology is the development of systems. However, there needs to be an equal emphasis on how well architecture performs and how performative qualities can be enhanced by informed design. [(6)]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

## 2- RESEARCH THEMES:

### *2-1 The laws of mathematical philosophy and thinking design*

The language of structural metal design, depend on Mathematical laws proportion, in particular, carry great importance in the design process of structural metal, presented in its primary elements, geometry, biomorphic forms, and calligraphy, which are all based on and ruled by the underlying geometric laws (proportions). It follows that the structural metal design principles are reflected in geometry. In other words, geometry plays a central [(7) (8)]

The design of metal structures light depends on the way in which the designer picks facets to sides design. The mathematical expression of the sensed and seen can be followed. The language of mathematics will be more readily accepted ...as each mathematical equation, although it is quantified correctly, it is not beautiful in the mathematical sense as each architectonic item although perfect in a constructive way; it is not good in an architectonic sense. [(9)]

The designer focuses on understanding the basic structural principles before going into details and calculations, whereas in engineering science, a structural understanding is developed through a synthesis of various analyses in detail using precise structural calculations. The latter requires a profound analytical study before a structural understanding of the whole can be achieved, while the former starts from a general structural understanding of the whole before going into a more profound understanding of the details. [(1o)]

Understanding structural as a part of a building means creating the sequence of steps, which are arranged in a way that a student will understand. These are the reasons why different forms of teaching (exercises - studio) are introduced gradually. [(11)] The light metal structure is a group of components that work together to accomplish a common goal when solving technical problems and the relationship between basic elements and subelements is important. Sub elements can also affect each other. [(12)]

The fundamental can be found in the understanding of design. In the 1930s, the design was developed based on the notions of a set, relation, and transformation. This development in design is usually evaluated as a step away from a visual geometry with its negative impact in averting a clearness of descriptive design. But on the other hand, this more abstract concept was an important step for universal applicability of design. David Hilbert developed the design in such an abstract way as a system of structures, three.

The philosopher Max Bense, Professor at the University of Stuttgart and at Ulm School of Design, used the structural understanding of design to develop an exact aesthetics as a basis for designing by analyzing the characteristics of aesthetic structures. Max Bense said in his “Aesthetica” (1954/1982): “It is easy to see that designate structures are general and abstract so that they are usable to the reproduction of physical as well as aesthetic structures.” We refer to this theoretic philosophical background for having a look at design processes. [(13)]

Secondary considerations such as aesthetics, law, economics and the environment may also be taken into account. In addition, there are structural and constructional requirements and limitations, which may affect the type of structure to be designed. [(14)] This stop involves a detailed consideration of the alternative solutions defined in the planning phase and results in the determination of the most suitable proportions, dimensions and details of the structural elements and connections for constructing each alternative structural arrangement being considered. [(15)]

There are new modes of practice where the realms of research design and development are seen as one. The knowledge passes osmotically from practice to academia, from teacher to student and from the future designer to the designer - academic. This is a vital skill of all designers, transporting the design of metal structures discourse and practice beyond any notion of egocentric space. [(16)]

### *2-2 Aesthetics of light metal structures*

The 'light metal structural' is considered as a three-dimensional composition. Hence, before studying the aesthetics of structures, certain fundamental concepts about composition have to be understood. When 'aesthetics of structures' are concerned, it cannot be studied in isolation, as it has links with many other areas such as art, architecture, philosophy, engineering, etc. [(17)]

Shape optimization, looks at the shape of the metal structure in a design domain, the shape boundaries to obtain an optimal solution. In this case, the optimization can reshape the material inside the domain. Optimization tools commonly used in the design are based on genetic algorithms, where principles from nature and natural selection can be used to identify the ideal design for specific criteria in a certain design domain design has a central part of the design, as well as a typical part of a designing curriculum. [(18)]

The design of the golden ratio is related to numerical series found frequently in the natural world. It simply follows the rule that the next number is the sum of the previous two numbers, as follows: 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, etc. The description of the golden mean features can be seen everywhere in the forms of nature. One of the formed signal products of the sacred means is the spiral, commonly found in nature.

Proportional design regulates primarily the order of design process. It is needed to create the forms by which we acknowledge the beauty in design forms. The beauty of proportions is based on the simple design of regular polygons with a set of ratios of side lengths to diagonals (such as O2, O3, O4, O5, and y). These design proportions are used to quantify aesthetic qualities. They can be achieved by means of algorithms of visual math as an objective ground which can be founded on design and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

proportions The Beauty in proportions has a key function in constituting them because it forms the underlying structure of order versus diversity, establishing systematic design principles. [19]

The approach here is to find designed abstractions for individual aesthetics. By drawing conclusions from our emotions we can arrive at a qualitative basis for the design. Often the abstract design view leads to new concepts, new variations or allows intuitive ideas to be verified. There are designers whose visions of aesthetics produce designs with very strong structural sensibility and innovative ideas. Examples of these architects include Buckminster Fuller, whose philosophical ideas about holistic design, synergetic and design - led to innovative structures such as the geodesic dome. [20]

Design light metal structural comes from the area of artistic feeling and fine art. Constructional thinking and structural design are ways to materialise the first idea. Inspiration can come from designers who look for a border between pure thought and its materialisation, between a work and a mass. The emotive and intuitive (artistic) side of a creative process in studios requires more intimate communication than education about facts. One has to be reminded that without an active approach and student creativity, satisfying results cannot be achieved. To motivate and encourage brainstorming methods is very important, as well as to assume responsibility, self-reflection, presentation and self-evaluation of a student. [21]

***2-3 Mathematics and Computer Aided Manufacturing:***

Recently, designers have become interested in the design basics of single-and multilayer free form structures. Existing literature has been motivated by problems in the fabrication of steel and other structures and mostly aims at the realizations of free forms [22]

The developments were software to model nubs surfaces designal equations for advanced design projects. Computer Aided Manufacturing have both drastically altered the industrial paradigm of mass standardization.

The use of computational and design orms geometric bears a great potential to advance the field design of free form metals structure light , which is currently emerging at the border of differential design, computational design and architectural design. [23]

The actual trends in architecture show more and more complex, irregular and seemingly “non-geometric” forms. It seems that the digital tools help the users to create anything possible. The more spectacular a building appears, often without perceptible structures, the better and more innovative it is evaluated.

Given these new computationally driven methods, all too often desiners have quickly abandoned formal disciplines of design and instead turned to reductive principles for describing seemingly complex forms.

In addition to totally weakening any integrity of formal logic that may have lead to the initial formation, this computationally aided process falsely assumes that as long as it is cad/camed the resultant form will gain integrity.

The increased stability of triangular elements comparedto quads was one of the advantages of geodesic domes. Later, Computer-Aided Design, by augmenting and replacing the more traditional tools for modeling freeform light metal structure, not only enabled more complex structures, but even created a demand for them. Designers suddenly had significantly more powerful design tools at their disposal, which in turn drove designers to meet the challenge and again provide means of coste _ective production. Last, but not least, the gap between design freedom and production was the main driving force for designians and computer scientists to found the interdisciplinary research field of light metal structure. [24]

***2-4 Free form surface and polyhedral surfaces in architecture***

Structure of single- and multi-layer constructions can be analyzed with mesh parallelism as the main tool. This concept allows us to encode the existence of node axes and offsets in a discrete Gauss image, and to define discrete curvatures in a natural way. Optimization in the linear space of meshes parallel to a given mesh yields a modeling tool. A particularly important and interesting type of meshes is those possessing edge offsets. [25]

Polyhedral surfaces – structures from flat panels In order to realize a freeform surface in light metal structure, one often breaks it into smaller elements, called panels. Certainly, flat panels are the easiest and cheapest to produce and thus surfaces composed of flat panels, so-called polyhedral surfaces or polyhedral meshes play a key role in deign light metal structural design. [26]

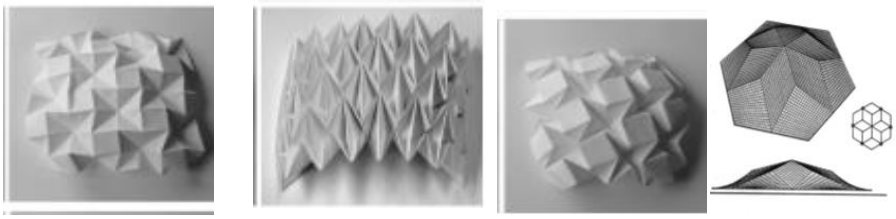
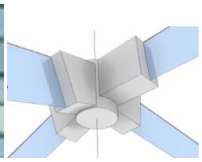


Figure 1 patern freeform surface and polyhedral surfaces

Designers face the problem of approximating the given surface by a mesh with planar faces. If triangle meshes are employed, the design part of the solution of this problem consists of choosing the vertices and deciding which vertices to connect by edges. If faces can have more than three vertices, this approximation task is not so simple, because the condition of planar faces is no longer fulfilled automatically. [27]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

As one example of a development we mention tensegrity structures (consisting of elements of various kinds, e.g. cables allowing only tension, or struts only allowing compression), the term coined by Buckminster Fuller in 1960. A recent example is the 2009 Kurilpa Bridge, the world's largest tensegrity bridge. This topic is very rich also from the designal viewpoint. A current trend is the use of free forms. [28]



- The support structure consists of the node axes.
- The support structure associated with a mesh.
- The support structures yields torsion free node.

**Figure 2**: clear Triangle meshes used in free form metal structure.that design by Chris Williams and Foster+Partners for the Great Court Roof of the British Museum in London

The idea was to produce a canopy that was delicate and unobtrusive, avoiding the need for columns within the courtyard. The result is a stunningly unique form geometrical. Although it looks simple and delicate, it represents a feat of modern. The fine steel lattice is constructed from custom-made steel box beams joined at six-way nodes. According to Stephen Brown, Buro Happold's principal engineer on the project, the design of the roof's toroidal framing was defined using a customized form-generating computer program.

The roof shape is curved to a tight radius of approximately 50 meters, which means it can act much like a dome, while imposing minimal loads onto the existing surrounding structures. [29] Design meshes with planar faces, circular meshes, and conical meshes by subdivision and optimization, and also how to approximate a given shape by a circular or conical mesh. As input for such mesh optimization algorithms any mesh aligned along a network of principal curvature. [30]

The junction of the roof and the Reading Room uses a ring of 20 composite steel columns, which align with the room's original cast-iron frame and triangle meshes are ubiquitously used in design. Their use in light metal structural has deferent reasons and deferent aspects become important_ Edges are often visible and smoothness (or lack of smoothness) of mesh poly lines is an important part of the design. This is in contrast with design processing and computer graphics, where triangle meshes serve as amorphous representations of shapes a role.

***2-5 Methodology design studio light metals structures***

The students are taught Studio Design how to design elements light metal structure where students are given structure elements. To design a small construction, but are also not given the designs to assemble their elements in compelling ways. The goal of the design has focused more on the aesthetics, or ''form'' of a metal structure, stability efficiency, or its 'function' and the method of teaching integration in during design studio from level 1 to level 2 where the design studio light metal structural teaches the basics of metal design which emphasize more on design concepts. So the analysis focuses on integration of various subjects such as students‟ awareness of their weakness on the structural understanding and integration of structure in their design projects.

The analysis focuses on method of design and studio progress where the integration of technical and creative parts takes place. In the design of light metal structural, two basic approaches are most commonly employed currently, which is topology optimization based design and cellular metal structure design from nature.

**Topology optimization is a designal optimization methodology** devplopment think design that achieves an optimized design by redistributing elements within a given design space with the objectives of maximizing/minimizing certain criteria such as weight, stiffness, compliance and conductivity while being subjected to design constraints. Unlike sizing optimization and shape optimization, topology optimization does not prescribe design topology that determined as following:.

1. Metal structural function expresses the type of load transfer that occurs in a structural element: axial or parallel transfer of force, or axial or parallel transfer of moment. Each structural element is required to perform its structural function to enable the structural system to bring the load to

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

the supports. The consequences of performing a structural function on the structural form of an element are expressed.

2. Metal structural order reveals the structural relations between different structural elements for a specific load case: it shows which element is supported by which other elements. It brings to the fore the paths a load follow throughout the system of structural elements to its supports.
3. Metal structural dimensions this leads to five major types of structural dimensions: one for each type of structural function, where axial transfer of force is split into tension and compression. This means that expressing the characteristics of structural dimensions also reveals the underlying characteristics of structural functions that each element needs to perform.
4. Metal structural design possibilities link each element and its characteristics of structural dimensions with a wide range of possible structural design solutions. Analytical cellular models were established to provide computationally efficient property design, and various design factors such as size effect, stress concentration and connection effect were also investigated in order to provide additional design guidelines.

In general unit cell geometries can be designed with cubic, possess good spatial symmetries and could therefore be further simplified during the design modeling. The material properties are constants, they could be readily substituted into material property functions, therefore potentially allows for multi scale hierarchical designs with the cellular metal structures with material/process design factored incorporated. Also, for cellular metal structures that could not be treated as beam networks, other existing solid structure modeling theories could be used, which further increases the flexibility of this design methodology. This study fouce of students' use design during an industry based senior design project and a study of students' use design during a solve design problem. Designal thinking behavior was investigated using five fundamental aspects designal thinking: The level of governing laws, which is a abstract level of the structure, expresses the integration of a set of structural laws. The level of structural structure phenomenon, a level related to the visual body and the organization of vocabulary within a specific functional framework.

.

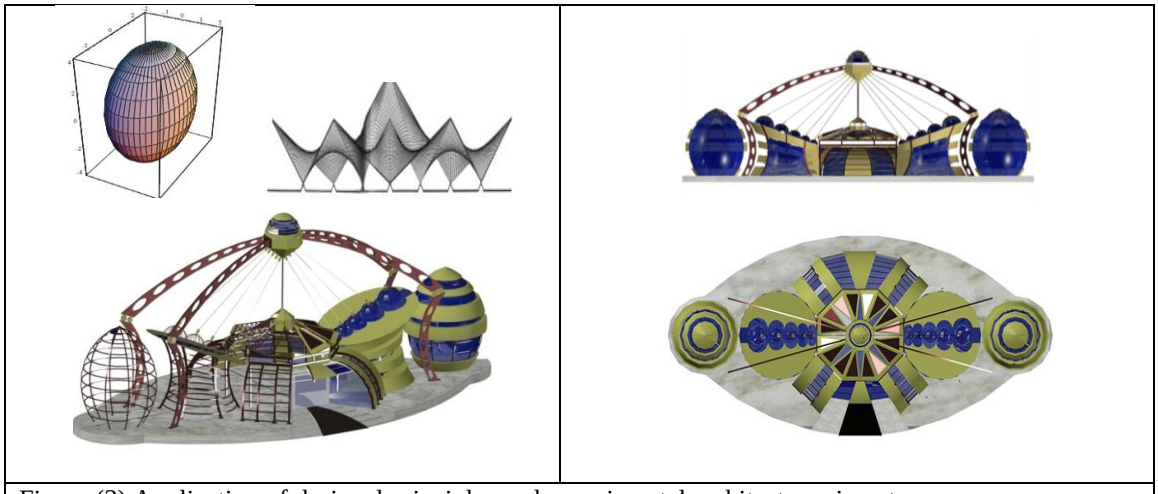


Figure (3) Application of designal principles and experimental architectures in nature.

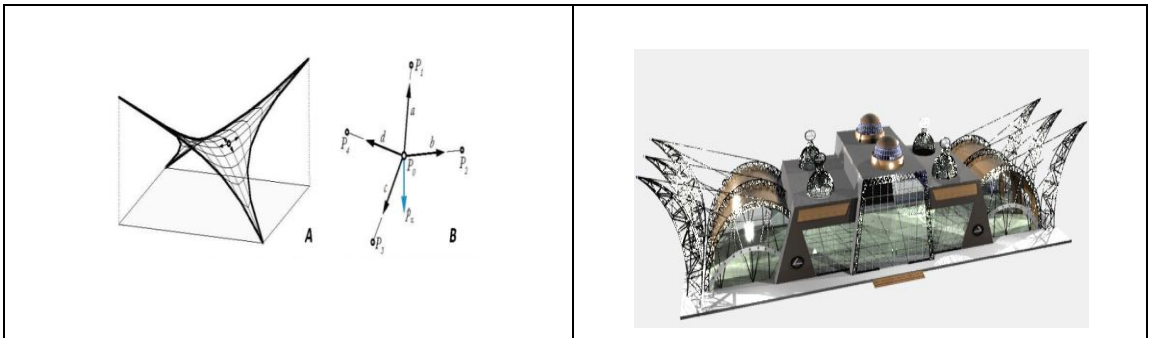



Figure (4 ). Cellular metal structure design approach for design in general.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

The design of periodic cellular metal structures with unit cell is analogous to the design of 3D metal structure patterns. When only one type of unit cell regular is used for the designs, regardless of the actual unit cell design, the regular bounding volume of the unit cell must satisfy design requirement. Again the structural elements (members and connections) need to be situated as the way that the members and connections are assembled will vary from project to project and this will impact the way that they are designed and detailed. *Critical vocabulary* infers that the selected elements, phrases and terms are essential to the development of this structural language to the point that they will form the basis for criticism in the discipline. The very basic typical connections in structural applications will form a solid base from which to explore more complex phrase-based variations which themselves can be used in a reductive or analytical way to verify if the transfer of forces is correct. But to develop a vocabulary, these must be extended and developed to have agency in design. The proposal stage of *design of metal structures* concept depends on a certain case in what level is the own structural solution and in what level the structure will be transposed into a design expression. Then, verification follows: repetitive imaginary dialogue between individual parts of design. This step is important for creative students.

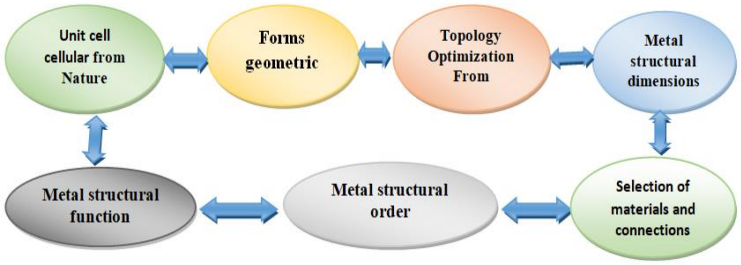


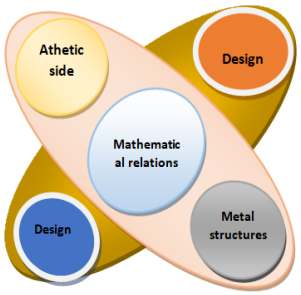

Figure ( 5 ). Integrated methodology design circumstances design studio light Metals structures.

These suggest is a “no numbers” exploration of the language of steel structures. Elements or connections will be assembled into larger components such as trusses, floors or frames), into larger system elements of the structure and ultimately into construction. The proposed language expresses essential design characteristics of this design proposition by revealing its underlying structural logic. It is at the centre of a design proposition, and demarcates the range of design possibilities this proposition entails. Functionality of structural creativity in nature with the ability to draw laws that govern the stability of natural forms and aims to create logic of form that can be used in the production process. In actual practice the calculations of structural members will be done by the structural signers while the student proposes the image of the structure. The sizes and proportion of the structural elements are a compromise between the actual sizes required by the designer.

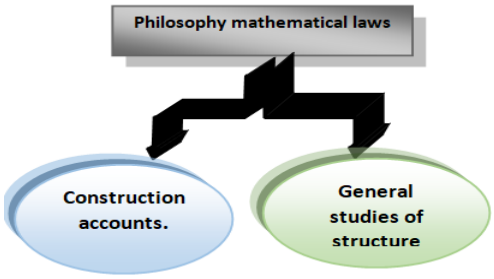
## 3- RESULTS AND DISCUSSIONS

Research studies of the relation between design foundations of the light metal structures and mathematical laws and aesthetic values. The results of research are the following:-

- Mathematical relations are considered the connected circle between design, Athetic side, designer and metal structures.

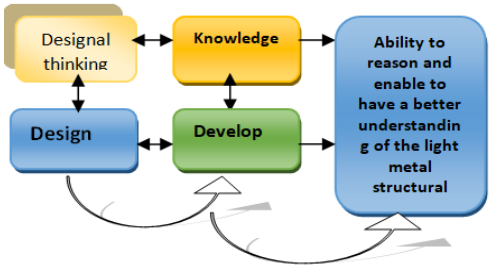



- Philosophy mathematical laws of metal structure design are applying by two ways: general studies of structure and scienceof numbers or quantity which used in construction accounts.




- The students which use a designal content knowledge and designal thinking in a number of ways in designing and in developing, have the ability to reason and enable to have a better understanding of the light metal structural.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019




- The students should be allowed to give rational ideas on how the supportive members may look like, based on reasoning derived from their designal and unit nature cell cellular metal structure with designal. Instead their explorative nature be curbed when students because of their disability to calculate the forces and sizes of structural members.
- With advancement metal structure design, the starts students still lacks adequate understanding with the process-material property relationship of the lightweight structures, this require understanding simple lightweight structures.
- This think direction has been inspired by the work of the smart design group, which promoted the use of parametric design and scripting for mastering design complexity in design light metal structural from a methodology perspective design.
- Aesthetic judgments might vary concerning the emotions, intellectual opinions, will, desires, culture, preferences, values, subconscious behaviour, conscious decision, training, instinct, or some complex combination of all these. Therefore we are asking for fundamentals for design processes, in order to escape from an arbitrary design and finding a rational basis for design processes
- Students must explore the flexibilities provided by the designal. Well, this should not be new to designer, but it appears different if we look at this fundamental knowledge within the design process.
- In a design light metal structures based on a triangle mesh, typically six beams meet in a connection meshes for the actual construction, torsion-free nodes are preferred.
- The aim is to identify a system - scheme and to understand a principle. It is up to the experience of a teacher to choose examples within the group of students, which will cover a certain typological scope of examples
- Should be teaching architecture, hard knowledge through soft methods facilitated in fact, hard methods should be used only marginally, to show that product performance calculations are also necessary.
- Design for design studio work come from looking for ideas and a concept when the indication of a structure solution can come only after the evaluation of many concepts.
- Adaptive design light metal structures can be characterized by four key attributes: Dynamic, Transformable, Bio-inspired and Intelligence.

## 4- REFERENCE

[1] Ján Ilkovič, Ľubica Ilkovičová & Robert Špaček: To think in architecture, to feel in structure: Teaching Structural Design in the Faculty of Architecture - Global Journal of Engineering Education - Volume 16, Number 2, 2014 p59-
[2] Lauren. Beghini, Alessandro Beghini: Connecting architecture and engineering through structural topology optimization - journal homepage: www.elsevier.com/locate/engstruct Engineering Structures 59 (2014) P 716–726
[3] L. Yang1, O. L. A. Harrysson2, D.: Design for Additively Manufactured Lightweight Structure: A Perspective -Solid Freeform Fabrication 2016: Proceedings of the 26th Annual International .p 2166
[4] Boake, T. THE "CSI" FORENSIC APPROACH: Re-visioning Steel Education to Enable Creative 3D Thinking University of Waterloo, Canada (2012) p 1-8
[5] Loai M. Dabbourn: The underlying structure of design process for Islamic geometric patterns- · Geometric proportions- December 2012 https://www.researchgate.net/publication/257737466
[6] Philip Beesley, Sascha Hastings: White Papers - Riverside Architectural Press and Living Architecture Systems Group 2019 p 320: 335
[7] Peter R. Cromwell, 'Islamic geometric designs from the Topkapı Scroll II: a modular design system', J. Math and the Arts 4 (2010) 119–136.
[8] L. Yang. Experimental-assisted design development for an octahedral cellular metal structure using additive manufacturing. Rapid Prototyping Journal. 21(2015), p2: 168
[9] Ergun Akleman :Society of the Arts, Mathematics, and Architecture Special Issue on Shape Modeling International -17-21 June 2019 Vancouver Canada p22-30
[10] Ergun Akleman :Society of the Arts, Mathematics, and Architecture Special Issue on Shape Modeling International -17-21 June 2019 Vancouver Canada p22-30
[11] Point Sketch and Force PAD. In M. Voyatzaki, ed. Emerging Possibilities of Testing and Simulation, Methods and Techniques in Contemporary Construction Teaching . Mons, 22-24 November 2007. Thessaloniki: Charis, pp. 259–264
[12] L. Yang1, O. L. A. Harrysson2, D.: Design for Additively Manufactured Lightweight Structure: A Perspective -Solid Freeform Fabrication 2016: Proceedings of the 26th Annual International .p 2165: 2180
[13] Cornelie Leopold*: Structural and design concepts for architectural design processes Boletim da Aproged nº 32 - Setembro de 2015 ISSN 2183-1947
[14] Lauren L. Beghini, Alessandro Beghini: Connecting architecture and engineering through structural topology optimization - journal homepage: www.elsevier.com/locate/engstruct Engineering Structures 59 (2014) P 716–726
[15] Manual Design Criteria for Bridges and Other Structures February 2018
[16] Philip Beesley, Sascha Hastings : White Papers - Riverside Architectural Press and Living Architecture Systems Group 2019 p 320: 335
[17] Chandana Kulasuriya :Aesthetics in Structures -The Institution of Engineers, Sri Lanka - Vol. XXXVIII, No. 03, pp. 45-61, 2005
[18] American Society for Engineering Education, Engineering Students'formdesignal Thinking: In the Wild and with a Lab-based Task 2007
[19] Loai M. Dabbourn. The underlying structure of design process for Islamicdesign patterns- ·design proportions- December 2012 https://www.researchgate.net/publication/257737466 P383-391
[20] Lauren L. Beghini, Alessandro Beghini: Connecting architecture and engineering through structural topology optimization - journal homepage: www.elsevier.com/locate/engstruct Engineering Structures 59 (2014) P 716–726
[21] Ján Ilkovič, Ľubica Ilkovičová & Robert Špaček: To think in architecture, to feel in structure: Teaching Structural Design in the Faculty of Architecture - Global Journal of Engineering Education - Volume 16, Number 2, 2014 p59-65

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 12, December-2019

[22] Pottmann, H., Liu, Y., Wallner, J., Bobenko, A.,design of Multi-layer Freeform Structures for Architecture -ACM Trans. Graph. 26, 3, Article 65 (July 2007),
[23] Helmut Pottmann1, Alexander Schiftner1 design of Architectural Free form Structures Internat. Math. Nachrichten Nr. 209 (2008), 15–28
[24] Helmut Pottmann a,b, Michael Eigensatz c, :Architecturaldesign-Preprint submitted to Computers & Graphics December 29, 2014
[25] Pottmann, H., Liu, Y., Wallner, J., Bobenko, A.,design of Multi-layer Freeform Structures for Architecture -ACM Trans. Graph. 26, 3, Article 65 (July 2007), p
[26] Boake, T. THE "CSI" FORENSIC APPROACH: Re-visioning Steel Education to Enable Creative 3D Thinking University of Waterloo, Canada (2012) p 1-8
[27] Pottmann, H., Liu, Y., Wallner, J., Bobenko, A.,design of Multi-layer Freeform Structures for Architecture -ACM Trans. Graph. 26, 3, Article 65 (July 2007), p
[28] Helmut Pottmann a,b, Michael Eigensatz c, :Architecturaldesign-Preprint submitted to Computers & Graphics December 29, 2014
[29] Pottmann, H., Liu, Y., Wallner, J., Bobenko, A.,design of Multi-layer Freeform Structures for Architecture -ACM Trans. Graph. 26, 3, Article 65 (July 2007),
[30] Pottmann, H., Liu, Y., Wallner, J., Bobenko, A.,design of Multi-layer Freeform Structures for Architecture -ACM Trans. Graph. 26, 3, Article 65 (July 2007), p 5