Low-tech or High-tech?
“cut.enoid.tower” - three times two facets of irregularity

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SUMMARY

Do membrane structures belong to low-tech or high-tech products?

The concept of low-tech is mostly understood as the counterpart to high-tech and refers to technology which is developed under the aspects of easy function, easy production, easy service, robustness and easy maintenance. In most cases low-tech-solutions bear a huge amount of intelligence deriving from long-lasting processes of trial and error. Therefore the majority of our structural systems is based on low-tech considerations. Building with textiles is one of them.

This paper looks into the question above by the means of the realized, experimental structure “cut.enoid.tower”*[*]* a complex system of combined structural principles. The three aspects – Irregularity as a result of combined structural systems, Irregularity in detail as a result of geometrical necessity and Irregularity as a feature of architectural complexity – spanning from the global design approach to detailing, general rules (low-tech) used tools for formfinding (high-tech) and the final result (low-tech) are highlighted.

Keywords: Catenoid, minimal surface, membrane, irregularity, lattice structure, tower, selforganizing forms, architecture and structure, aesthetics,

CONTEXT

The objectives of Structural Membranes 2013 are to collect and disseminate state-of-the-art research and technology for design, analysis, construction and maintenance of textile and inflatable structures. In this context we face a question, which represents a balancing act between structural/formal principles originating in selforganizing processes and developments on the material- and software sector:

Do membrane structures belong to low-tech or high-tech products?

The concept of low-tech is mostly understood as the counterpart to high-tech and refers to technology which is developed under the aspects of easy function, easy production, easy service, robustness and easy maintenance. So low-tech in general does not give information on the grade of intelligence behind a certain technology or product but focuses on the output under above mentioned aspects. In most cases low-tech-solutions bear a huge amount of intelligence deriving from long-lasting processes of trial and error. Regarding architecture and structural engineering the majority of our structural systems is based on low-tech considerations. So low-tech can be described as a design and construction philosophy. Vice versa the newest scientific knowledge is often used for the development of low-tech and therefore complex solutions. Low-tech products are mostly as well characterized by the consideration of aspects like of least material consumption, least (human) energy consumption and waste prevention – aspects of sustainability. Building technologies are mostly connected to a special kind of material, its specific material properties and the way the material is used - the technique. Arches build from stone, hanging bridges build from robes or even from grass like the Qeswachaka hanging bridge in Cuzco, Peru or forming bundles and bending them like the March-Arabs are just a few examples of the utilisation of simple active principles. Building with textiles is one of them.

This paper looks into the question above by the means of the realized, experimental structure "cut.enoid.tower"[*] a complex system of combined structural principles. These structural principles, which can be declared as tension- (minimal surface catenoids), compression- (pin-joint-columns) and actively bent (plates) elements, simultaneously represent low-tech solutions each for itself as well as combined system, which is constituted from interacting elements. Especially the procedure of iterative formfinding respectively finding a structural equilibrium that fulfills other functional and architectural needs and its simulation is part of a high-tech approach using sophisticated tools.

The result of this design approach appears as formal output and can be summarized in three aspects bearing both facets low-tech and high-tech. In this regard the "cut.enoid.tower" highlights the three aspects – Irregularity as a result of combined structural systems, Irregularity in detail as a result of geometrical necessity and Irregularity as a feature of architectural complexity – spanning from the global design approach to detailing with a special focus on the general rules (low-tech) used tools for formfinding (high-tech) and the final result (low-tech).

What is understood by irregular?

Regularity – a misunderstood Simplification?

Usually irregularity is described as behavior that breaches the rule, as deviance, deviation - deviate behavior, not characterized by a fixed principle or rate.

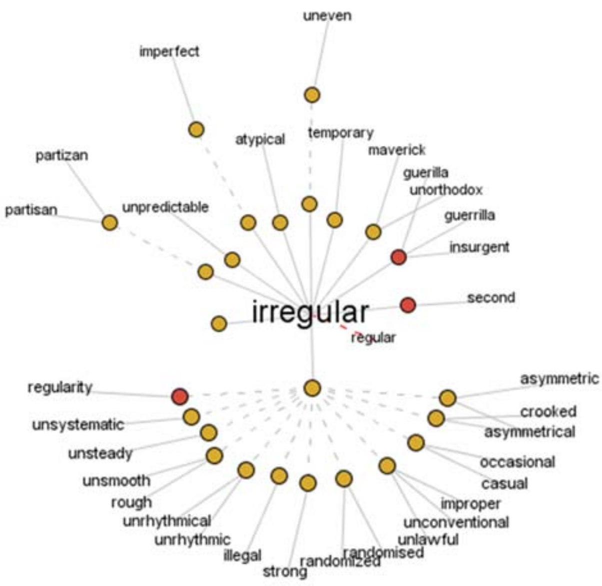


Fig. 01 Traditional Definition of "irregular"

Fig. 02 Irregular Natural Pattern

As part of the environment we are surrounded by irregularity. This phenomenon can be found in every field, every scale, in various forms, etc. Based on this insight irregularity can be seen as a complex, not on the first hand comprehensible order.

To demonstrate the two different respectively mutual contradictory definitions following question may be asked. What would be the correct attribute of a square? On one hand each change of a side length creates a variation into a rectangle, in other words each rectangle is a deviation of a square. So the square is the regular geometry, the rectangles an irregular one. On the other hand we could argue that there are infinite rectangles. Therefore both, length and width, having the same dimension must be a very special case. From this point of view labeling the square "regular" could be a misunderstood simplification.

In architecture a move from geometrically clear forms towards more and more complex and individual space creating forms can be recognized. This phenomenon is directly correlated with emerging technologies, which provide the possibility of these kinds of design, in terms of architectural and structural design –, allow for better exchange between designer and producer in terms of data transfer as well as for more complex calculation and production of spatial structures.

Today we can also recognize a change in the perception of irregularity for example as asymmetric geometry in our society. Not too long ago seen as imperfection and not following “divine proportions” irregularity is rated customized and individual today.

This development in design also raises the question if irregularity is produced or received by both - architects and engineers, meaning that irregularity on one hand leads to a higher degree of freedom in the creation of spatial structures – producing – and on the other hand irregularity represents the result of functional, structural, etc. parameters – receiving -.

1 Irregularity as a result of combined structural systems

In general “cut.enoid.tower” merges different structural members like tension- (minimal surface catenoids), compression- (pin-joint-columns) and actively bent (plates) elements into an overall system. Analogue and digital simulation of these combined structural systems result in (seemingly) irregularity, which is necessary in order to achieve a state of equilibrium [***].

1.1 Tension Elements - Minimal Surface Catenoids

Catenoids are the only rotational bodies that can be a minimal surface in soapfilm-analogy at the same time.[01] For the „cut.enoid.tower” we can recognize a “spinning” (Fig.04, 10, 11) respectively a “branching” (Fig.12,13) version of prestressed, tension-only, minimal surface catenoid[2,3] , which are spanning seemingly “freely” shaped cut-outs of the wooden plates. In fact the cut.enoid.tower`s cut outs were generated by the overall size and distance of the wooden plates, the possible “radius” at given distance, which can be equated with a given height, the position and the eventual collision of catenoid and pin-joint columns. So their irregular “free” shape is caused by several reasons and has further impact on the active-bending-behaviour of the plates. Referring to the fundamental rules in the generation of catenoids we know that its maximum height is directly related to its radius. Further on we know that in contrast to shifted boundaries boundary conditions which are deviating from primal forms like circle or square have little influence on the general shape of the catenoid. [01] So the change of boundary geometry has marginal effect on the surface, which shows fluent forms. On the other hand the boundary is the only geometry that can be visually exactly captured.

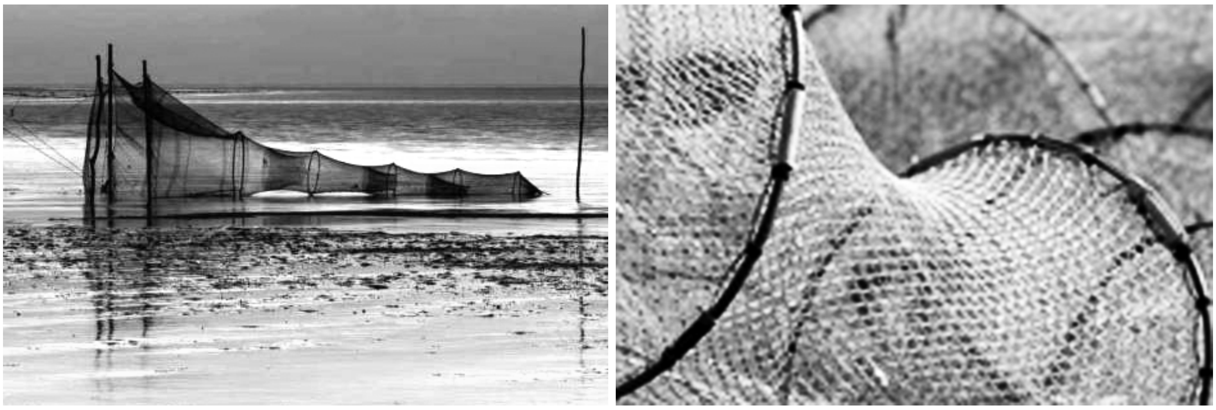


Fig. 03 Traditional, low-tech “catenoids” for fishing purposes

Fig. 04 Different stages in the design process of the boundary of the “spinning” catenoid

1.2 Irregularly Arranged, Skew-Whiff Hinged Columns

A lattice-like structure, consisting of irregularly arranged, skew-whiff hinged columns, represents the compression-counterpart to the tension-catenoids. Compared to conventional lattice structures, here pin-joint members do not meet in their reference points or axes. When joining two or more flat or curved surfaces by the placement of hinged, linear elements all preliminary physical and digital experiments showed that a minimum number of six skew-whiff hinged columns are necessary to achieve a stable structure. [**] The placement constitutes an arbitrary irregularity, but exactly this irregular arrangement generates a stable structural equilibrium locking all directions in space.

Due to its longitudinal proportion the plates of „cut.enoid.tower" are connected by more than six hinged columns. In the design phase six hinged columns basically locked the structure. Step by step columns were added but also removed if possible.

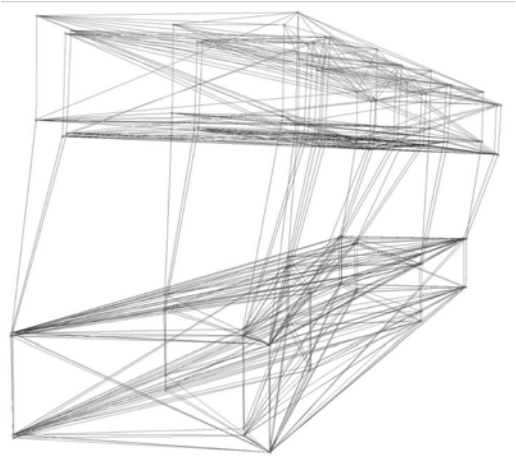


Fig. 05 Iterative process of finding the positions for hinged columns

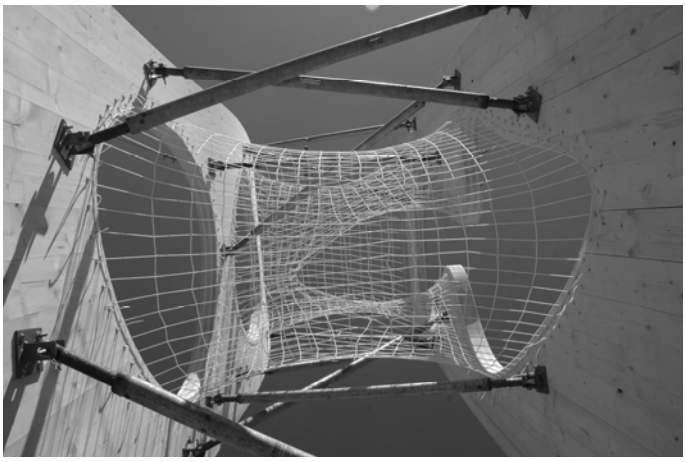


Fig. 06 Irregularly arranged, skew-whiff hinged columns in finished structure

1.3 Irregularity – A State of Equilibrium

Generating a distorted, irregular appearance of the wooden plates simultaneously caused and combined with the interaction of skew-whiff hinged columns and different versions of prestressed, tension-only catenoids, which are spanning "freely" shaped cut-outs, a state of equilibrium can be gained. The distortion of the wooden plates can be investigated as a special case of active bending, which is defined as follows:

"Active-bending is applied intentional for the shaping process to achieve a predefined geometry. It is one advantage of actively-bent elements that the same straight/flat elements can be used for different curvatures. Actively-bent elements are defined as elements that are transformed from the stress-free start-geometry to their end-geometry by elastic bending. Possible elements are beams and plates with a usually straight respectively flat start-geometry." [5]

The unity of all elements and forces can be read as deflections which were simulated, found and analyzed by means of a series of physical and digital models (Fig.07).

A modification of only one element or parameter of the system will cause a variation of the whole tower-structure in order to find a new equilibrium. This procedure was run through in an iterative process involving the size of the wooden plates, the geometrical boundary preconditions for the catenoids, their position and eventual collision with hinged columns and the correlation of tension- and compression-members, which is visualized by the distortion of the plates, as well as functional issues like climbing (Fig.08).

The distorted geometry again represents a new starting position – we face a classical "the chicken or the egg causality dilemma that has to be solved in constant feedback loops.

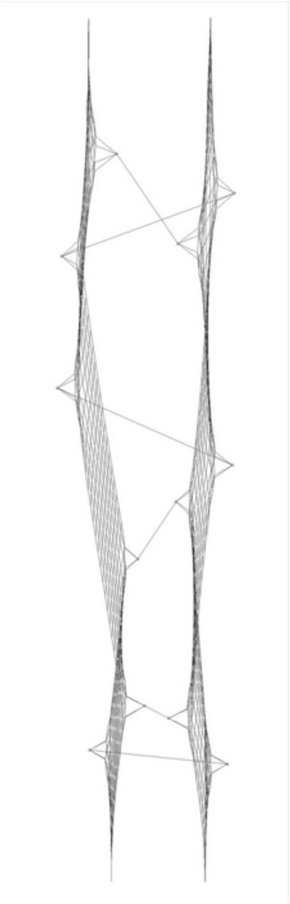


Fig. 07 Simulation of displacement of wooden plates

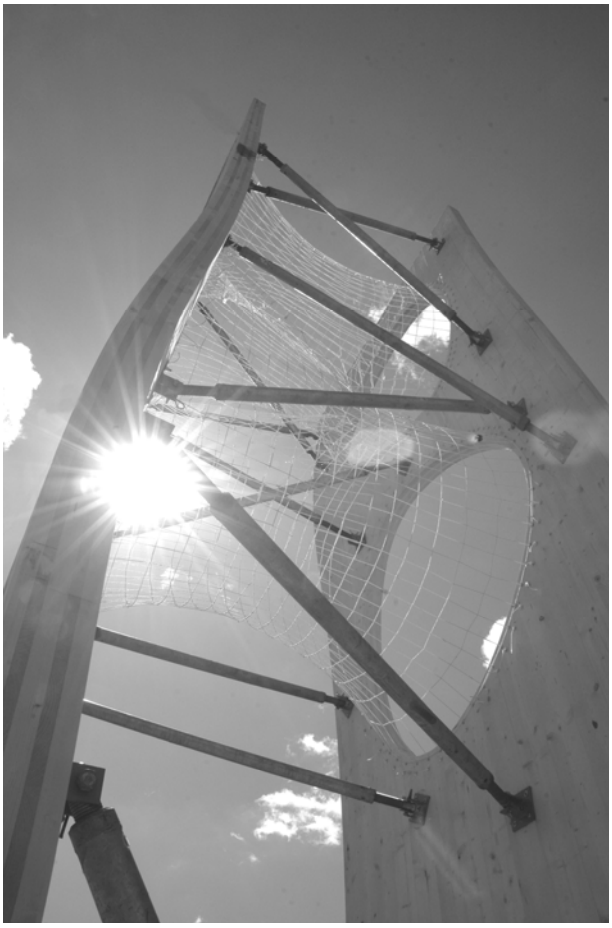


Fig. 08 Displacement of wooden plates in realized structure

2 Irregularity in detail as a result of geometrical necessity

Details of column-heads or the manufacturing of the nets show the simultaneous use of high-tech and low-tech strategies. Low-tech knotting techniques meet high-tech-tools like Grasshopper scripts in order to solve the geometrical positioning of column-heads or the analysis and assessment of the prestressed minimal surface nets. The aspect of irregularity arises as a geometrical phenomenon.

2.1 Irregular Meshes of Minimal Surface Catenoids

As mentioned, catenoids are basically rotational bodies generated by a catenary rotating around a vertical axis. Postulated a simulation / realization as a 3d mesh, this would allow for many identical mesh faces. As soon as the geometry of the boundaries is not identical, respectively different from a primal form and/or arranged in a shifted way each single mesh face turns out to be unique.

The “spinning” (Fig.10,11) and the “branching” (Fig.12,13) catenoid of „cut.enoid.tower” were executed as cable-net structures with an average mesh-size of 10x10cm. After the digital formfinding using for example Rhino Membrane and Forten all mesh-lines respectively all intersection-points were numbered and their distance calculated. This was done with the help of a grasshopper script which exported all data into excel-sheets. These lists with more than 11300 distances between the 5697 intersection points of the cable net were the basis for the fabrication process – an irreplaceable advantage of high-tech tools. Similarly, over-length for connection details and knots as well as a compensation factor in accordance to the elongation of material behavior under prestress were digitally applied.

In the realization process 1,5km of 4mm high-performance yachting robes (Fig.09) meeting in 5697 knots were tied by students in order to produce the unique shapes of the minimal surface catenoids (Fig.09). In advance several techniques and types of knots were tested according to their frictionproperties (to keep knots in place), material use, degree of difficulty to produce, error-rate in the production process, time consumption for the manufacture and so on. “The Ashley Book of Knots”, which is showing and explaining 3900 time- and field-tested knots, was of inestimable help – a low-tech basis for a high-tech process to achieve a low-tech product in the end (Fig.09).

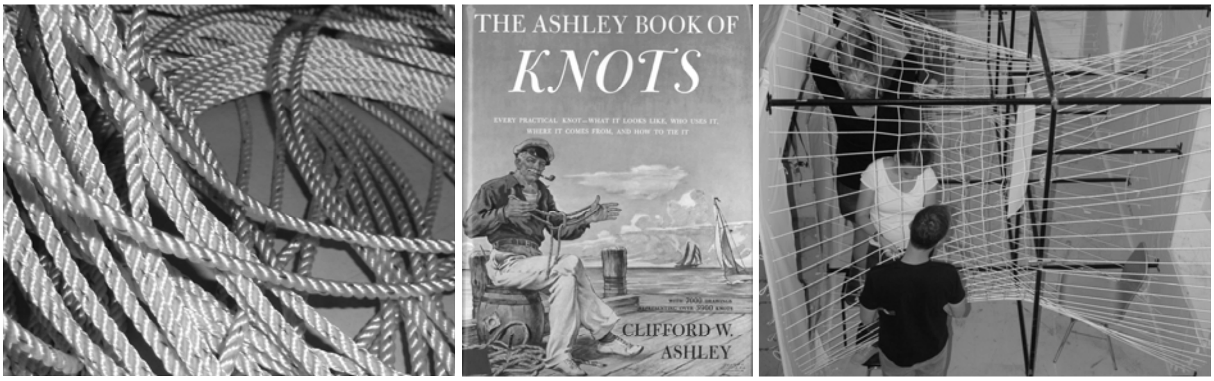


Fig. 09 1,5km of 4mm high-performance “Liros prestretch“ yachting robes meeting in 5697 knots according to techniques from “The Ashley Book of Knots”

Fig. 10 Spatial impression of “spinning”

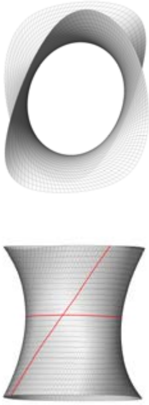


Fig. 11 Comparison of right-angled and “spinning” mesh-pattern(right)

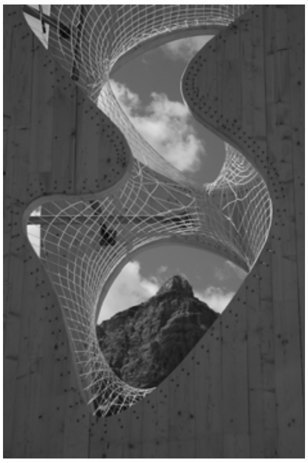


Fig. 12 Realized ”branching”catenoid

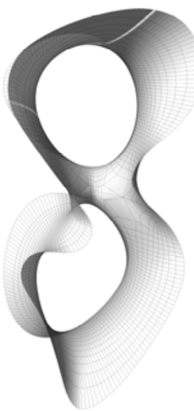
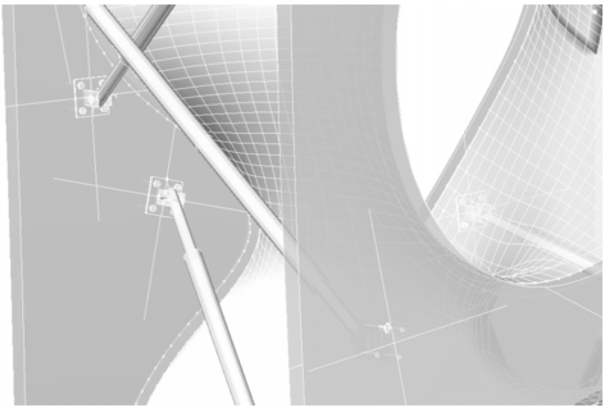


Fig. 13 boxer-short-like boundary conditions of ”branching” catenoid

2.2 Curved Surfaces Seated Position and Rotation of Head-Plates

The wooden plates of „cut.enoid.tower” are deformed simultaneously actively bent (Fig.08) by tension and compression elements. This deflections cause constantly different distances between the plates. Since the connection between plates and columns is designed as uni-axial hinge the right, solidly on the curved surfaces seated position and rotation of the head-plates of all skew-whiff members as well as the real length of all skew-whiff hinged columns have to be found.

By means of Grasshopper scripts a plain was rotated according to the (structural) system point and angle of the skew-whiff column (Fig.14). Together with the system point the UV values gave information on the right position and rotation of the head-plates (Fig.15).



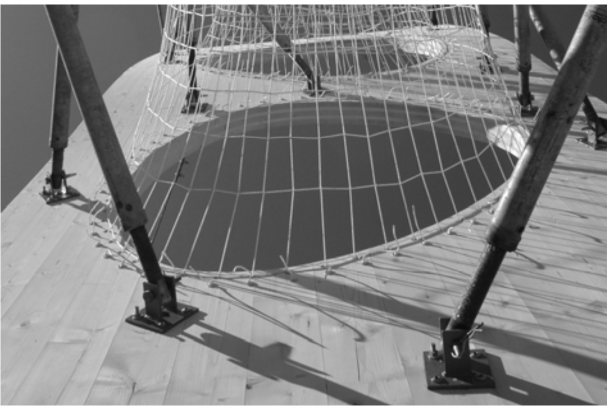


Fig. 14 Simulation of position and rotation of the head-plates of all skew-whiff members

Fig. 15 Position and rotation of the head-plates in realized structure

3 Irregularity as a feature of architectural complexity

The unity and equilibrium of all elements and forces within the structure of „cut.enoid.tower" can be perceived as irregularity. Similar to selforganizing forms most beholders experience this kind of irregularity as a logical result. In the case of „cut.enoid.tower" the design was considering architectural, structural and functional issues like climbing, relaxing and enjoying the stunning scenery as well as maximum wind speed of about 140km/h (Fig.16). Deriving from these different demands, which can be specified as parameters, visual, geometrical, functional, structural and architectural unity was generated. This complex unity, consisting of mostly quite simple low-tech components and merged together by high-tech tools, is shown as irregular structure, pattern, arrangement, visual impression, …

Fig. 16 "cut.enoid.tower" - impression of the finished structure on 1650m above sea level

CONCLUSION

The question if membrane structures were belonging to low-tech or high-tech products cannot definitely be answered. Focusing on single components of the design, we can assign them to low-tech-issues. Present, mainly digital tools allow for combining several parameters and components. Merging these components into an overall design asks for high-tech approaches, since a simultaneous handling of several parameters is subject of complex processes.

Complex structures of this kind are brought into equilibrium respecting all parameters and physical boundary conditions. Outside interferences or changes of involved elements reactivate the whole formfinding process.

At the moment, structural and architectural irregularities seem to be produced, sometimes implementing random algorithm in order to create irregular structures. This random irregularity is afterwards re-optimized in a structural sense [7,8].

Our experimental model investigations on physical and digital basis again and again have shown that the phenomena of irregularity have two major coalesce aspects:

- Irregularity can significantly increase the freedom in design.
- Irregularity frequently increases, sometimes it is essential for structural efficiency.

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