Utilizing Palm Rachis for Eco-Friendly and Flexible Construction in Egypt

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Presentation Road Map

Problem & Hypothesis
- Why Palm Rachis is the new alternative construction Material?

Literature Review
- Previous Experiences of Building with Palm Rachis.

Knowledge Gap
- New Challenges and Objectives.

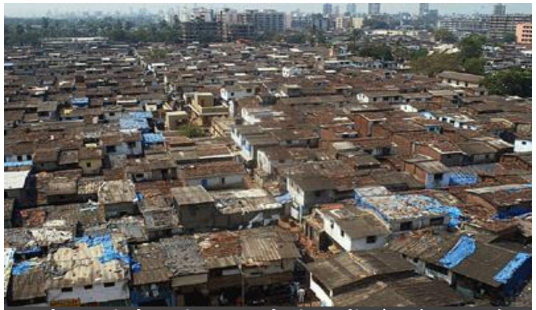
Methodology
- Scaled Physical Model.
- Mechanical Properties Measurements.
- Digital Structure Simulation

Discussion
- Structural Development.
- Physical Model.
- Mechanical Properties Measurement
- Digital Simulation

Conclusion

Problem & Hypothesis

Problem & Hypothesis



Dharavi slum in Mumbai, India (Taher and Ibrahim, 2014)

Informal Expansion on Agricultural Land in Egypt (Khalifa, 2011)

Burning Straw Crops in Egypt (Leitzel, 2011)

Construction Industry vs. Environment: Unsafe Consumption of Non-Renewable Resources

Globally:

The Construction Industry consumes more than 40% of the global and non-renewable resources
+
Emits over 30% of the greenhouse gas emissions according to the UN Estimations

Locally:

High economic costs of non – renewable conventional building material
↓
Employment of wastes and junks as fast and cheap materials in order to build shelters
+
un-safe and non-biodegradable **toxic for man and environment**

+

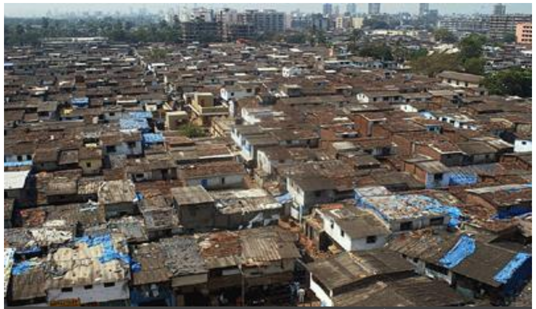
Disintegrated Waste Management in Egypt

Burning the Agricultural Pruning Residues
↓
Emits over 60% of CO emissions in Egypt.
+
The Black Cloud since 1999

Pruning Residues include:

- Rice, Wheat and Barley Straw.
- Date Palm Pruning Residues

Problem & Hypothesis



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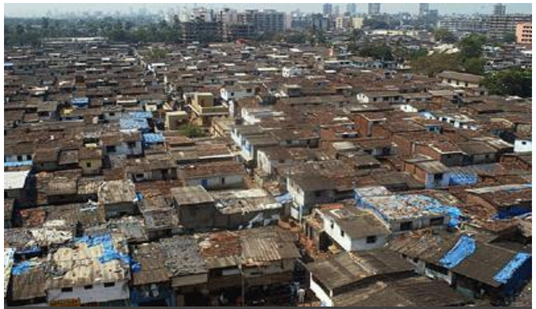

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Pruning Residues include:

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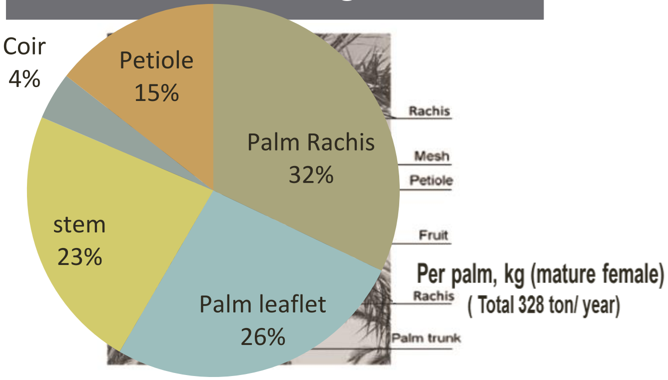
- Date Palm Pruning Residues

Date Palm Pruning Residues as alternative building materials:

- Date Palm Rachis is one of the most important agricultural residues that are used traditionally in cheap and rural construction.
- Contemporary Eco-Lodges and Cultural museums utilize Date Palm Rachis, as Date Palm Rachis enriches the traditional originality of such Cultural and Environmental Tourism oriented projects.



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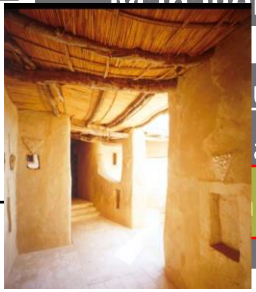

Roofing by Palm Rachis Adrere Amellal Eco-Lodge(Alamuddin, 2001)

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Pruning Residues

Date Palm Pruning Residues as alternative building materials:

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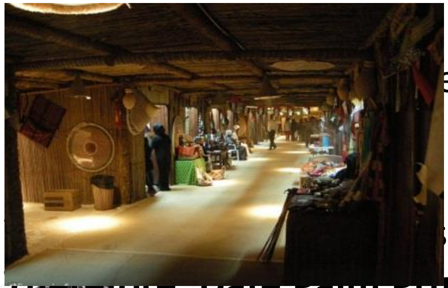


Roofing by Palm Rachis in in Qattara Heritage Village in UAE (Hesty, 2014)

Palm Trunk Beams used for traditional roofing in Sinai.(Ibrahim, 2010)

- es and Cultural museu Date Palm Rachis enr such Cultural and Envi

- Therefore, Date Palm Pruning Residues enjoy the familiarity and Technical Heritage in Egypt.

Literature Review

Literature Review

1. Post and Beam Palm Rachis Bundles



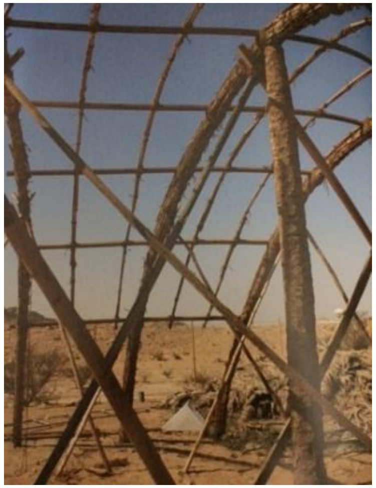
- The construction of the 2x3m shade took only 4 hours It was very simple, fast and cheap construction that was built entirely by the author and the local workers in Qayat Village, Minya, Egypt.

However, there were 3 main disadvantages: the deflection that happened to the beams of the longer side while achieving low flexibility and small spans, and the full dependence on ropes in the connection which could be stronger if the connections depended on friction or interlocking between the bundles at the corners. These added to the challenge of the structural system design.

Literature Review

2. **Arched Palm Midribs Bundles** (Piesik, 2012)





- The vault was constructed using arched bundles of palm Rachis with circular cross section of 20cm diameter to cover a span of 13 m. Due to the small cross section; every arch was supported by 4 palm trunks on intervals of 3.25 approximately.
- However, in spite of the significance of that new construction system, it’s criticized of using internal trunks every 3.25 m which can interrupt the continuity of the multifunctional activities inside.

Literature Review

3. **Cross Arched Palm Midribs Bundles** (Sheehan et al., 2015)

- The idea is based on assigning 2 perpendicular grids of arched Palm Rachis where the load of each arch is totally distributed on the perpendicular grid of arches. The grid made a 8x8m module that was repeated in 3 rows and 3 columns to make a 24x24 module .
- In spite of using no trunks as internal vertical supporters, future extensions are limited to repeating whole modules, while at the same time; the continuity of the space is interrupted by the ends of the arches at the edges of the modules. In addition to that, the tent-like form that was used due to the double curvature in the structure will be difficult to comply with the rural context in Egypt.

Literature Review

The Natural Bending shape of Rachis

Full Deflection at rope connection and beams while covering small span.

Dependence on internal supporters which interrupt the function flexibility

Repetition of modules is required for future expansions

Literature Review

Lack of mechanical properties and digital structural analysis.

Full Dependence on Physical Model

↓

Design according to the onsite structural behaviour of the members

Unpredictable forces (wind, seismic forces) are not considered.

↓

Dependence on strict grids and internal vertical supports

Decreasing the structural integrity and flexibility of the form and function

Knowledge Gap

Lack of mechanical properties and digital structural analysis.

Full Dependence on Physical Model

Knowledge Gap:

It lies within examining a system **both physically and digitally** in order to design palm rachis based structural systems that are **efficient in material usage and space**, in addition to achieving **flexibility in form and future extensions and function without using internal vertical supports.**

Decreasing the structural integrity and flexibility of the form and function

Knowledge Gap: New Challenges and Objectives.

Structural integrity	Form and function flexibility	Simple yet Durable connections
• Wide and Open Spans • Suitable for Multi -functional Halls	• Free of strict grids • Free of internal supports	• Non-dependent solely on ropes. • Climate Resistant

Methodology

Scaled Physical Modelling	Mechanical Properties Measurement	Digital Structural Simulation
• Imitate the steps of real construction.	• European Standard EN 408 : 2003	• SAP2000

Discussion

Discussion

- **Structural Development**
  1. **Structural Integrity: Arched Space Truss**

2D Arch to 3D Dome

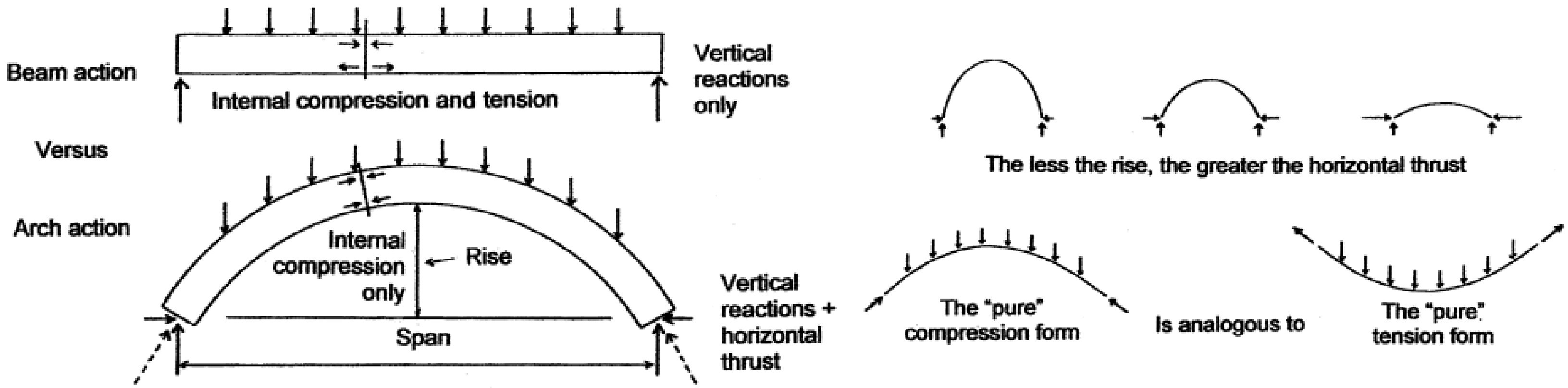
- This solution is originally imitates the main concept of **<u>Space Trusses.</u>**

2D Truss to 3D Truss

However, in spite of the flexibility, lightness and integrity of the system, the main challenge is the design of joints.

Discussion

- **Structural Development**
  2. **Friction Connection: Parabolic Arch**



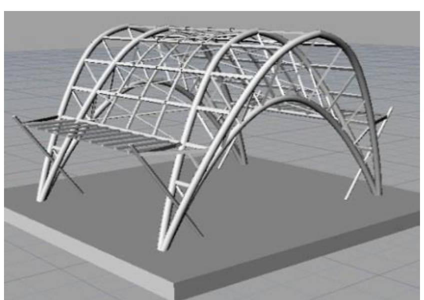
- The basic concept in the arch is the development of a spanning structure through the use of only internal compression.
- An ideal arch depends on transforming the bending moments into compression forces only while loads are distributed evenly. This arch's shape takes the pure compression form i.e. a **parabola.**
- The compression forces in the parabolic arch allow using **friction connections.**

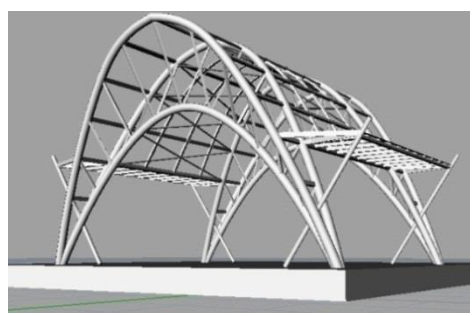
Discussion

- **Structural Development**
  3. **Suggested Structural System**

Arched Palm Rachis Bundles :2D Arch

Arched Palm Rachis Bundles: 3D Dome



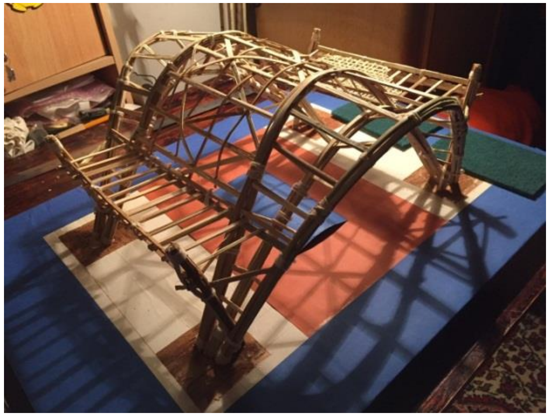


Arched Space Truss

Discussion

- Physical Model Procedures

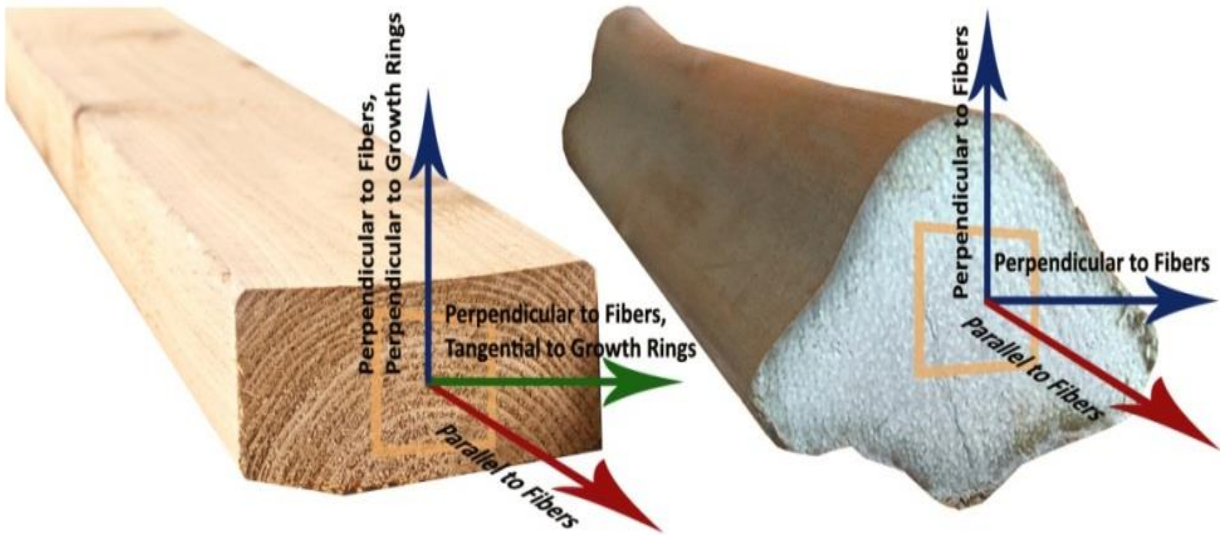
- The physical model was chosen to be in 1:20 scale due to the available space limitation.



- The used material is dried palm rachis that were sliced as thin as possible to imitate the true members.

Discussion

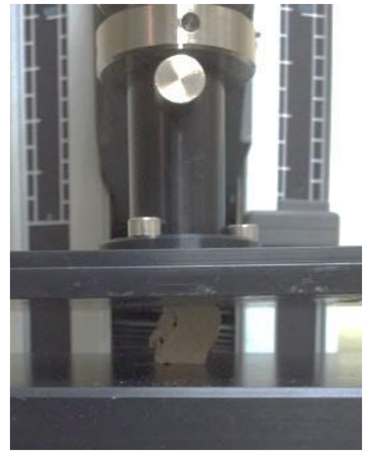
- Mechanical Properties Measurements



- Natural materials such as wood are usually treated as an orthotropic material, supposing in the linear orthotropic model that there're 3 planes of symmetry in the 3 axes of the material.
- The tangential and radial directions in wood are identified according to their intersection with the annual growth rings. However, due to the lack of growth rings in palm midribs, the mechanical properties which are perpendicular to fibres are similar in both tangential and radial directions

Discussion

- Mechanical Properties Measurements



- The longitudinal modulus of Elasticity, the perpendicular modulus of Elasticity and Shear modulus were measured using compression (EN 408-2003).

- Due to the complexity of the measurements, the Poisson Ratio was assumed according to the properties of Spruce Wood (Green et al, 2010) that was proven to be close to Date Palm Midribs (Elmously,2001).

Discussion

- Mechanical Properties Measurements

Property Description	Value
Longitudinal Modulus of Elasticity –E_L	10287.8 MPa
Tangential Modulus of Elasticity-E_T	105.45 Mpa
Radial Modulus of Elasticity-E_R	105.45 MPa
Longitudinal-Radial Poisson's Ratio-V_{LR}	0.372
Longitudinal-Tangential Poisson's Ratio-V_{LT}	0.467
Radial-Tangential Poisson's Ratio-V_{RT}	0.435
Longitudinal-Radial Shear Modulus-G_{LR}	109.2 MPa
Longitudinal-Tangential Shear Modulus-G_{LT}	109.2 MPa
Radial-Tangential Shear Modulus-G_{RT}	39.05 MPa
Mass per Unit Volume	0.95 gm/cm^3
Effective Yield Stress	45 MPa
Effective Tensile Stress	54 MPa

Mechanical Properties of Date Palm Rachis according to EN408-2003 (Moisture Content=7%)

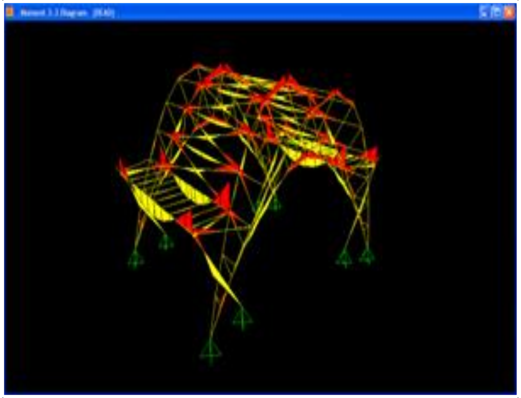
Discussion

- **Digital Simulation**
  - The materials properties were defined manually into SAP2000
  - The values of Normal Forces and Bending Moments due to Dead Loads and Wind Loads combined were calculated in order to check the safety of the system while covering variable spans.
  - The connections were assigned to be firm friction connections and the bundles were assigned to be fully coherent.
  - The structural check was based on Allowable Stress Design method (ASD), where the actual loads are used in structural calculations, because of the lack of safety adjustments of Palm Rachis as a relatively new structural material.
  - The structural check used the combined stress interaction (CSI) equation: $\left[\frac{f_c}{F_c}\right]^2 + \left[\frac{f_a}{F_a}\right]^2 \leq 1$

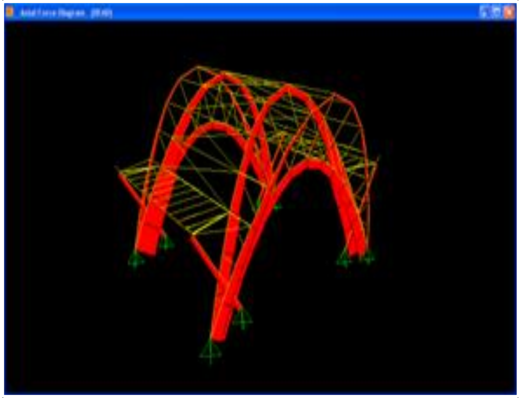
(f_a is the actual axial load (compression or tension), F_a is the allowable axial load (compression or tension), f_b is the actual bending load and F_b is the allowable bending load.)

Discussion

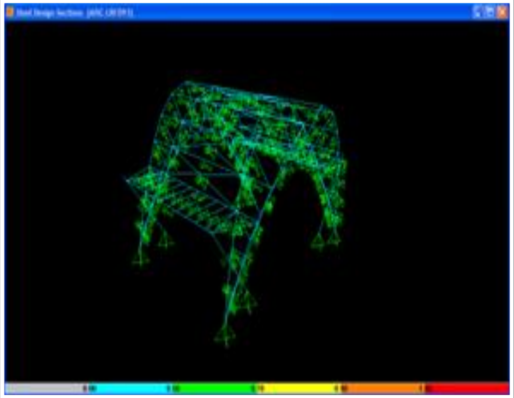
- **Digital Simulation**
  - **Clear Covered Span = 8m.**



Bending Moment Visualization (Red - +ve, Yellow- -ve)



Normal Forces Visualization(Red- Compression, Yellow – Tension)

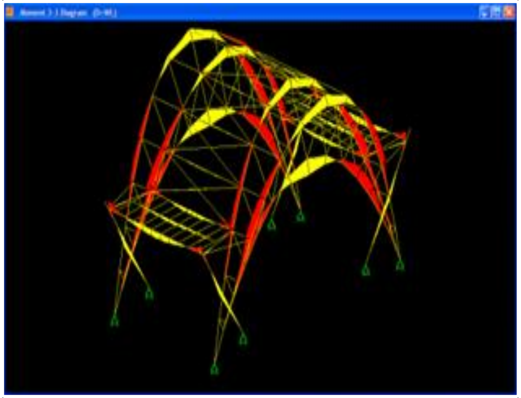


Stresses Check (Green-Safe, Red-Unsafe)

SAFE !

Discussion

- **Digital Simulation**
  - **Clear Covered Span = 10m.**



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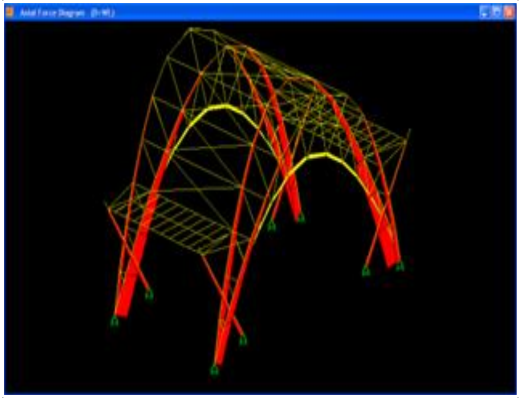

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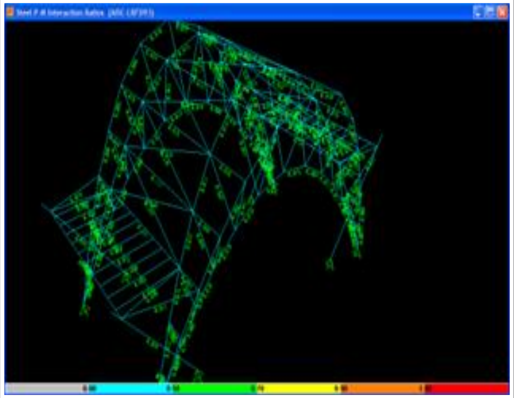
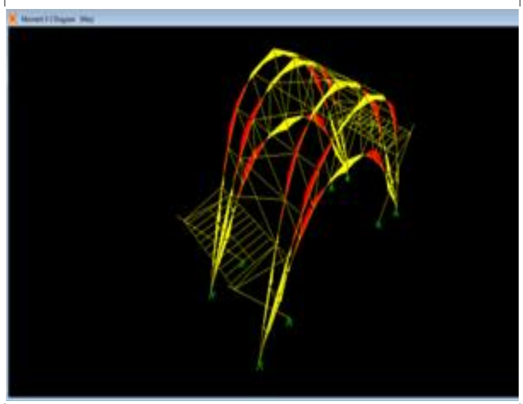


Stresses Check (Green-Safe, Red-Unsafe)

SAFE !

Discussion

- **Digital Simulation**
  - **Clear Covered Span = 16m.**



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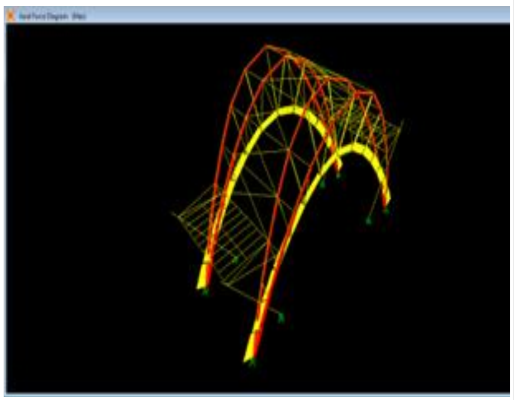

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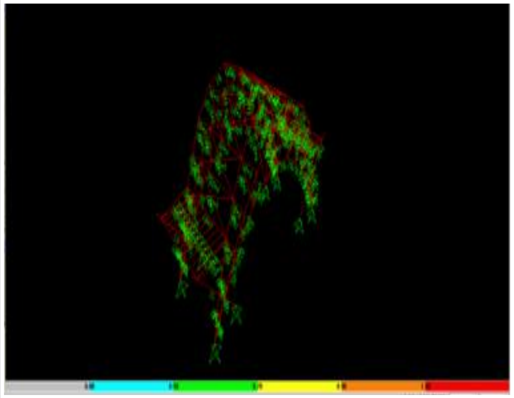

Stresses Check (Green-Safe, Red-Unsafe)

UNSAFE！

Conclusion

Conclusion

- Date Palm Rachis is a promising material in terms of construction. However, the resulting systems were not characterised by high flexibility or integrity.

- Therefore, the parabolic arched space truss structure was designed using Date Palm Rachis in order to introduce a versatile structure that can be used to cover multifunctional halls and public activities.

- The scaled physical model was constructed in order to predict the ease of construction and durability. The model proves to be simple, fast and required economic amounts of materials relatively. The connections prove to be highly durable under reasonable pressure.

- The results from the digital simulation showed that the system is highly recommended to cover spans up to 12m. In addition to that, the majority of the normal forces along the members are compression, which means that friction connections are suitable for the structure as long as the used arches are parabolic.

- This system can be used for multifunctional public halls such as markets, sport halls and recreational areas. This system provides the necessary flexibility, simplicity of connections and structural integrity, while depending on simple construction utilizing the highly available Date Palm Rachis.

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Thank you