TEAM
CENTRAL
Aakanksha (CM)
Stanford University
India

Xiaoxi (MEP)
Stanford University
China

Gabe (SE)
Stanford University
USA

Harry (BIM M)
Loughborough University
United Kingdom

Tim (LCFM)
Bauhaus-Universität Weimar
Germany

Weronika (ARCH)
Architecture University of Warsaw
Poland

Kostas (SE)
Technical University of Denmark
Greece
Site Map
Surroundings

Educational Buildings
Residential Buildings
Medical Facilities
Commercial Buildings
Restaurants

150 Yard Radius
Surroundings

7AM - 12PM

3 - 6 PM
Climate

**Temperature**
Summer 1% design temperature: 93 °F
Winter 99% design temperature: 37 °F

**Relative Humidity**
Summer - dehumidification
Winter - humidification

MAX
MIN
California Climate Zone 9
Site Conditions

**Precipitation**
Semi – arid area,
Scarce rainfall
Most rainfall from Dec. to Mar.

**Sunshine**
3,200 hours of sunshine per year
More than 50% of the time skies are clear or partly cloudy.
Hazards

- Earthquake Risk Category II
- Wildfire Risk

- Wind speed, snow loads not limiting factors in design
Site Challenges

- Earthquake
- Wildfire
- Traffic
- Air Pollution
- Public
WINTER QUARTER DEVELOPMENT
Big Idea 1: Treehouse
Big Idea 2: Spotlight
## Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Treehouse</th>
<th>Treehouse</th>
<th>Spotlight</th>
<th>Spotlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor Quality</td>
<td>PW + VAV</td>
<td>BRBF + ACB</td>
<td>BI + VAV</td>
<td>BRBF + ACB</td>
</tr>
<tr>
<td>WOW -Factor</td>
<td>4,57</td>
<td>6,19</td>
<td>5,53</td>
<td>5,63</td>
</tr>
<tr>
<td>Life Cycle Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
Goal 1 | NATURE
Goal 1 | NATURE

Playfull

Creative

Oasis
Goal 2 | PEOPLE
Goal 2 | PEOPLE

Learning

Collaboration

Collaboration
Goal 3 | SIMPLICITY
Goal 3 | SIMPLICITY

- Design
- Build
- Operate
Goal 4 | DESIGNED FOR LIFE
Goal 4 | DESIGNED FOR LIFE

Use    Repair    Disassembly    Cost
TREE
HOUSE
Form Exploration

30 k sqft

3 k sqft

27 k sqft

33 k sqft
Treehouse: Prefab Synergies

Simple By Design

- Orthogonal Form
- Simple Connections
- Uniformity
- Low Skill Assembly / Disassembly
- Workable Materials

- Repeatability
- Standardisation
- Low Skill Onsite Assembly
- Reduced Wastage
Moving to Prefabrication

- Congested Site
- Sensitive Area

- Enhanced Quality
- Increased Safety
- Faster Construction
- Cheaper Construction
Mass Timber

Carbon Sequestration
Light Weight - Strong
Offsite Construction

Increased Construction Speed
High Tolerance
Fire Resistance
Treehouse: Aspects

Informal Character

Simple Design

Assembly / Dissassembly

Place to escape to

Sustainability

Intimacy With Nature

Flexibility

Value
Treehouse
## Potential Solutions

<table>
<thead>
<tr>
<th>Volumetric / Modular</th>
<th>Half Volumetric / Modular</th>
<th>Kit Of Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest Reduction In Onsite Labour</td>
<td>Reduction In On Site Labour</td>
<td>De-skilled &amp; Reduced Hazard.</td>
</tr>
<tr>
<td>Highest Quality</td>
<td>High Quality if Integrated</td>
<td>BI Quality Tolerance</td>
</tr>
<tr>
<td>Maximum Wastage</td>
<td>Rework Wastage</td>
<td>Minimum Wastage</td>
</tr>
<tr>
<td>Highest Capital Cost</td>
<td>Medium Capital Cost</td>
<td>Low Capital Cost</td>
</tr>
</tbody>
</table>

**Potential Solutions**

- **Volumetric / Modular**
  - Highest Reduction In Onsite Labour
  - Highest Quality
  - Maximum Wastage
  - Highest Capital Cost

- **Half Volumetric / Modular**
  - Reduction In On Site Labour
  - High Quality if Integrated
  - Rework Wastage
  - Medium Capital Cost

- **Kit Of Parts**
  - De-skilled & Reduced Hazard.
  - BI Quality Tolerance
  - Minimum Wastage
  - Low Capital Cost
Route: Level -1
Human Perspective
Trees in the Atrium: Biophilia

O2

CO2

Potted Plant
Impacts for the M&O Costs

- Cutting and Consumption
- $4000 per year
- $125,000 over contract time
Route: Level -1
Find Rentable Area

- Connecting with other people
- Added Value over LifeCycle: $550,000
- Reduce annual Rent to $960,000
Impacts for the M&O Costs

- Cutting and Consumption
  - $4000 per year
- $125,000 over contract time
### Structural overlay: Level -1

#### Typical Elements

<table>
<thead>
<tr>
<th>Concrete column</th>
<th>Section [inch]</th>
<th>Length [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>18x18</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>18x18</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>18x24</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concrete beam</th>
<th>Section [inch]</th>
<th>Length [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12x24</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>12x24</td>
<td>28.5</td>
<td></td>
</tr>
<tr>
<td>16x32</td>
<td>47.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concrete Shear Wall</th>
<th>Section [inch]</th>
<th>Length [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5x12 [ft]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Concrete Construction

Precast
- Increased Labour Skill Set
- Modest Quality
- Minimum Wastage
- Economies of Scale
- Low Capital Cost
- Economies of Scale
- Lower Wastage / Low CO2

Cast In Situ
- Decreased Labour Skill Set
- Modest Quality
- Higher Wastage / Low CO2
- Higher Wastage / Low CO2
Structural overlay: Level -1

- Green: RC Beam
- Blue: RC Wall
- Red: RC Column
- Pink: PT Tendons
Mechanical Overlay: Level -1

- Supply Air
- Return Air
Auditorium: Level -1

Underfloor Air Distribution

- Supply Air
- Mechanical Room

- 4’6”
- 15’6”
- Return Air Plenum
Business Plan for Rentable Area

- Companies, Sperkers etc.
- Added Value over LifeCycle $1,900,000
- Reduce annual Rent to $900,000
Route: Level 1
North terrace
Structural overlay: Level 1

<table>
<thead>
<tr>
<th>Typical Elements</th>
<th>Section [inch]</th>
<th>Length [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glued Laminated Timber Column</td>
<td>10.5x11</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>10.5x15.125</td>
<td>32</td>
</tr>
<tr>
<td>Glued Laminated Timber Beam</td>
<td>8.5x15.125</td>
<td>9.5, 19, 27.5</td>
</tr>
<tr>
<td></td>
<td>10.5x15.125</td>
<td>38</td>
</tr>
<tr>
<td>Cross Laminated Timber Rocking/Shear Wall</td>
<td>9.5x13 [ft]</td>
<td></td>
</tr>
</tbody>
</table>
Timber Subassembly

STANDARDIZATION

+ GLT Column – 25 ft
+ GLT Beam – 9.5 / 19 ft

+ CLT floor & Roof –
  9.5 x 19ft / 9.5 x 9.5ft

Highest Reduction
In Onsite Labour

Highest Quality

Maximum Wastage

Highest Capital Cost

Sub-assembly
Timber Subassembly

Columns
34 X 25ft

Beams
34 X 19ft
28 X 9.5ft

Floor & Roof
128 X 19X9ft
4 X 9.5²ft
Mechanical Overlay: Level 1

Supply Air
Return Air
Mech. Shaft

Clash Avoidance
Route: Level 2
Internal Walls

Traditional Stud Wall

- Skilled Labour Force
- Reduced Quality
- Maximum Wastage
- Low Capital Cost

Prefabricated

- Deskilled Labour Force
- Highest Quality
- Minimum Wastage
- Economies of Scale
Route: Level 2
South Terrace
### Structural overlay: Level 2

<table>
<thead>
<tr>
<th>Typical Elements</th>
<th>Section [inch]</th>
<th>Length [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glued Laminated Timber Column</td>
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<td>12</td>
</tr>
<tr>
<td>Glued Laminated Timber Beam</td>
<td>8.5x15.125</td>
<td>9.5, 19, 27.5</td>
</tr>
<tr>
<td>Cross Laminated Timber Rocking/Shear Wall</td>
<td>9.5x13 [ft]</td>
<td></td>
</tr>
</tbody>
</table>
Level 2 Mechanical

Floor Sandwich

Supply Air
Return Air
Mech. Shaft

1’10”
10’2”
1’
False Ceiling Details

- False Ceiling
- CH.W.S pipe
- CH.W.R pipe
- Supply Duct
- Cable tray
- Return duct
MEP Rack & False Ceiling

- 30% Reduction in Labour On Site
- Improved Quality
- Weight; use of Steel.
- Increased Productivity

Manufacture

Ship

Lift
Route: Level 2
South Terrace
Goals

Goal 1 | NATURE

Goal 2 | PEOPLE

Goal 3 | SIMPLICITY

Goal 4 | DESIGNED FOR LIFE
AEC Challenges

Carbon Negative

IT Challenge

Industrialized Construction
Indoor Environmental Quality Focused Design

- Indoor Air Quality
- Visual Comfort
- Thermal Comfort
- Acoustic Comfort

Noise Level: 45db
Facade Optimization for Better Visual & Thermal Comfort

Indoor Environmental Quality

- Indoor Air Quality
- Thermal Comfort
- Visual Comfort
- Acoustic Comfort

Noise Level: 45db

Centra
Façade Optimization

Optimized Parameters
- Angle, $\alpha$
- Spacing, $S$
- Length, $L$

Evaluation Metric
- Solar Insolation
- Construction Cost
Data Integration Flow

Select Surfaces to Analyze
- Revit Sun Settings
- Climate
- Weather (from Revit Location)
- Select Shading Surfaces

Solar Radiation Analysis
- Select Surface
- Time Setup

Color and Value Range Normalization
- Reflectance
- Illuminance
- Contours
- Data Table

Dynamo

AUTODESK REVISION
Reduced Solar Insolation from Optimized Facade

<table>
<thead>
<tr>
<th>Angle, $\alpha$</th>
<th>Spacing, $S$</th>
<th>Length, $L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°</td>
<td>2'</td>
<td>1'</td>
</tr>
<tr>
<td>30°</td>
<td>2'6&quot;</td>
<td>1'6&quot;</td>
</tr>
<tr>
<td>45°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°</td>
<td></td>
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</tbody>
</table>

16 Design Options

Best Choice

60° 2'6" 1'6"

30% Reduction in Cumulative Solar Insolation
Mechanical Systems for Better Thermal Comfort

Indoor Environmental Quality

- Indoor Air Quality
- Visual Comfort
- Thermal Comfort
- Acoustic Comfort

Noise Level: 45db
Active Chilled Beam
- Cooling & Heating: Chilled/Hot water delivered to the coils in beams
- Ventilation: Dedicated Outdoor Air System (DOAS)
Energy Consumption

Winter

Spring
Building Energy Consumption Evolution

Energy Usage Intensity (EUI) Evolution

- Reduce Glazing Area
- Add shading device
- Add Daylight Control

ASHRAE 90.1 Benchmark

37.4
39.8
41.3
42.3
44.3
45.0
46.1
Impact to the M&O Costs

$ 2,100,000

$ 2,000,000

$ 1,880,000

$ 1,750,000
Roof Mounted PV-Panels + batteries

Consumed 350,000 kWh per year

Provides 370,000 kWh per year
Investment Cash Flow for PV-Panels

- **Payback Period**: 9 years
- **Savings (LCC)**: $850,000
## Building Gravity Loads

### LIVE LOADS

<table>
<thead>
<tr>
<th>Use</th>
<th>Load [psf]</th>
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</thead>
<tbody>
<tr>
<td>Offices</td>
<td>50</td>
</tr>
<tr>
<td>Computer Labs</td>
<td>100</td>
</tr>
<tr>
<td>Auditorium/Large Classroom</td>
<td>60</td>
</tr>
<tr>
<td>Lobby</td>
<td>100</td>
</tr>
<tr>
<td>Small Classroom</td>
<td>40</td>
</tr>
<tr>
<td>Corridors - 1st floor</td>
<td>100</td>
</tr>
<tr>
<td>Corridors - above 1st floor</td>
<td>80</td>
</tr>
<tr>
<td>Stairs</td>
<td>100</td>
</tr>
<tr>
<td>Storage</td>
<td>125</td>
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</table>

### TYPICAL DEAD LOAD

<table>
<thead>
<tr>
<th>Description</th>
<th>Load [psf]</th>
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<tbody>
<tr>
<td>Concrete Slab</td>
<td>50</td>
</tr>
<tr>
<td>CLT Panel</td>
<td>27.6</td>
</tr>
</tbody>
</table>

### LOAD COMBINATION (ASD)

<table>
<thead>
<tr>
<th>Description</th>
<th>Max Load [psf]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1<em>D+1</em>L</td>
<td>150</td>
</tr>
</tbody>
</table>
3D Gravity Load Analysis

Initial Displacement:
1.64” > 1.27”

*All beams 8.5”x15.125”

Final Displacement:
0.82” < 1.27”

*Change 38” beams at end of cantilevers to 10.5”x15.125”
Lateral Load Path diagram

- Lateral load
- Beam's transfer load
- Compression force
- Tension force
Modal Analysis

<table>
<thead>
<tr>
<th>Mode</th>
<th>UX</th>
<th>UY</th>
<th>RZ</th>
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<tr>
<td>1</td>
<td>0.0022</td>
<td>0.7545</td>
<td>0.0692</td>
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<tr>
<td>2</td>
<td>0.5058</td>
<td>0.0203</td>
<td>0.3031</td>
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<tr>
<td>3</td>
<td>0.3429</td>
<td>0.062</td>
<td>0.4677</td>
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</table>
Lateral Resisting System

Mass Timber

Light Weight - Strong

CLT Shear wall not ductile

Rocking/Pivoting Wall

Efficient System - Damage in predetermined regions
Rocking wall vs Pivoting wall

**Trade-off Analysis**

- **Fuses** - Energy Dissipation
- **Tendon** - Self-Centering
- **Base-Pin** - Avoid collateral damage
Final Rocking Wall Solution

- GLT Fail-safe columns
- CLT Wall
- Continuous PT-strand
- Krawinkler fuses
- Diaphragms prevent out of plane movement
Rocking Wall Load Path

**Seismic Forces:**

Overturning moment: Fuse + PT Strand

Shear force: Steel bracket at base

**Self-centering:** \( P_{PT} e_{PT} > P_F e_F \)
Final Rocking Wall Solution

- GLT Fail-safe columns
- CLT Wall
- Continuous PT-strand
- Krawinkler fuses
- Diaphragms prevent out of plane movement
Rocking Wall - Simulation

CLT Panel: Equivalent braced frame
Fuse: Multilinear Plastic Link Element
PT - Strand: Negative temperature load
Uplift movement: Gap Elements

Krawinkler fuse backbone curve used:
Site Conditions and Response Spectra

<table>
<thead>
<tr>
<th>Site Class</th>
<th>Risk Category</th>
<th>Category II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Class</td>
<td>C</td>
<td>Risk Category II</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Site Condition</th>
<th>Response Spectra</th>
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</thead>
<tbody>
<tr>
<td>SS</td>
<td>2.028</td>
</tr>
<tr>
<td>S1</td>
<td>0.726</td>
</tr>
<tr>
<td>SMS</td>
<td>2.433</td>
</tr>
<tr>
<td>SM1</td>
<td>1.016</td>
</tr>
<tr>
<td>SDS</td>
<td>1.622</td>
</tr>
<tr>
<td>SD1</td>
<td>0.677</td>
</tr>
</tbody>
</table>

Max interstory drift = 1.25” < 0.2*h

![Scaled Acceleration Response Spectra](image)

- 90% DBE Spectra
- Response Spectra Average

Period (s) vs. Sa/β
Rocking Wall: Constructability
Superstructure - Connections

Beam - Column

Beam - Girder

Timber Column - Concrete
Rocking Wall Health Monitoring

- Accelerometers for fuses
- Load cells for PT-strands
Risk Management for Structural System

- 90%

Functional and Operational
No Shutdown

- Without Risk Management
- With Risk Management

$800,000
$600,000
$400,000
$200,000
$ -
Safe Site for Pedestrians and Workers

Echo barrier H series with fabric filters

Mobile Dust Collector

Portable Trailers

Reusable Rolling Scaffolding

Interactive Hoardings - AR and

Electric Equipments

Earthquake Evacuation Plan
AI & Robotics Aided Excavation Process
Fuzor Logistics Supporting Process

Number of Trucks $\sim 194$
Average load time per bucket $\sim 105$ seconds
Crew size = 3 excluding drivers
Productivity per day $\sim 160$ cuyd
CO2 reduction $\sim 28\%$
Quick Substructure and Sub-assemblies

- Rebar Cage
- Polystyrene Formwork
- Concrete
- Supercap for levelling

**Alice Sequence**

**Assembly of Timber Sub-assembly**

- Crew size:
  - Fitting formwork = 4
  - Rebar Cage - Lifting = 3, Placing = 4
  - Welding = 3
  - Concreting = 4

- **Number of trucks for assemblies** = 112
- **CO2 reduction** ~ 60%
Prefabricated Elements

Timber Sub-assemblies

Panelized Walls (Interior & Exterior)

Prefab MEP utility cage with false ceiling

Finished Floor

Facade cage

Fuzor

Placement duration \( \sim 15 \) mins

Crew size -

Fitting = 3 Unloading = 3

Crane Operator = 2 Supervisor = 2
Manual vs Innovative Applications

Alice = 168 days

2 Cranes
Overtime
Parallel sequence

Manual = 191 days
Total Construction Cost = $8.69 M

$234 per sq ft
Sustainable Target Value (STV) Evolvement

Project Carbon Evolvement

<table>
<thead>
<tr>
<th>Project Carbon (kgCO2e)</th>
<th>Reduced Glazing Area</th>
<th>Add Shading Device</th>
<th>Add Daylight Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Target</td>
<td>5,368,459</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-9.7%  -5.2%  -7.7%

Final STV Result

Carbon (kgCO2e)

Water (kgH2O)

Energy (MJ)

53%  47%  28%
Life Cycle Costs

- Construction Costs: $8,690,000.00
- M & O Costs: $5,253,262.93
- Risk Costs: $1,178,375.32
- Replacement Costs: $1,777,193.29
- Interest: $2,630,576.65
Risk Management

- Earthquake
- Floting Rate
- Construction Delay
- Shortfall
- Wildfires
- Unpredictable

Legend:
- Without Risk Management
- With Risk Management

Values:
- Earthquake: $600,000
- Floting Rate: $400,000
- Construction Delay: $400,000
- Shortfall: $200,000
- Wildfires: $200,000
- Unpredictable: $200,000
Account for the Replacement Costs

Cash Flow

every year $ 75,000

Invest

Covered all Replacement Costs from that Account
Financial Indicators

DSCR Covered

LLCR Covered

Debt Service Cover Ratio
Loan Life Cover Ratio
Profitability

Payback Period: 19 years

Rent: $880,000
UCLA! Enjoy it!
Goal 1 | NATURE

Goal 2 | PEOPLE

Indoor Air Quality

Facade Optimization

Thermal Comfort

Mechanical Systems

Indoor Environmental Quality

Visual Comfort

Acoustic Comfort

Noise Level: 45db

Facade Optimization
Goal 3 | SIMPLICITY

Goal 4 | DESIGN FOR LIFE
AEC Challenges: IT

Dynamo

FUZOR
AEC Challenges: Industrialized Construction
**KPI - Precision in Placement of Elements**

- **Sequence**

- **RFID Tracking for Delivery**

- **Color-coding and Grid for Crane pick up**

- **QT50R-RH Series Sensors**
  Wireless Radar based Retro-wave Sensors Interact

- **Crane lifting the element with sensors**

- **Sensors on Base element**

---

<table>
<thead>
<tr>
<th>Element</th>
<th>Timber Sub-assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element Number</td>
<td>351-12</td>
</tr>
<tr>
<td>Location</td>
<td>Radio tower grid 3.2</td>
</tr>
<tr>
<td>Owner</td>
<td>4 columns and 4 elements</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Column length = 12</td>
</tr>
<tr>
<td>Subcontractor</td>
<td>Wood elements</td>
</tr>
<tr>
<td>Date delivered</td>
<td>2-26-2025</td>
</tr>
<tr>
<td>Date installation</td>
<td>1-26-2025</td>
</tr>
</tbody>
</table>
KPI - Drones Tracking Time, Quality and Cost

Drones
BIM-assisted image-based 3D & 4D reconstruction

Track

Activity = Placing Timber Sub-assembly
Crew = Count Hats for lifting and placing + Location + Time
Equipment = Crane lifting/placing Time + Location
Quality = Deviations of alignment + Fracture in material + Rework + Waste

Project Status

Productivity
KPI - Drones Ensuring Safety

Path Collision Detection
- Crane path
- Truck Route
- Worker Path
- Pedestrian Path

Send Instructions
Safety and Construction Process Instructions

Safety Equipments
- Interactive Safety Hat
- Supervisor
Bottlenecks in Project Execution

IDENTIFIED RISKS

MODIFICATIONS

RISK REDUCTION
WORKING IN SILOS!
In Need of Transformation

KOSTAS  GABE  
WERONIKA  TIM  XIAOXI  
HARRY  AAKANKSHA

Traditional Teamwork

- Process Quality
- Product Quality Risk
- Project Risk Index
- Functional Risk Index
- Communication Risk
- Meeting Risk
Integrated Team CENTRAL

Team Central

Architect (Archi)
Structural Engineer (SE)
Mechanical Engineer (MEP)
Building Information Modeling (BIM M)
Modeling (MODEL)

GABE
KOSTAS
HARRY
TIM
AAKANKSHA
WERONIKA
XIAOXI
Lesson Learned

“People skills! You NEED it b’cos no idea is better than a team idea.”

“Collaboration on a global scale requires coordination on a global scale”

“The key to Global teamwork is patience and putting aside your ego.”

“Good teamwork requires commitment from everyone.”

“Integrity is the key to success in everything, especially teamwork.”

“Everyone has different points of view”

“You always have less time than you think”
ARCH

David Bendet
Willem Kymmel
Jeff Daniels
Ron Elad
Martin Henriksen
Thank you!

Super Mentor
Dr. Renate Fruchter

Owners:
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