Designing a SOA Modular Housing Factory

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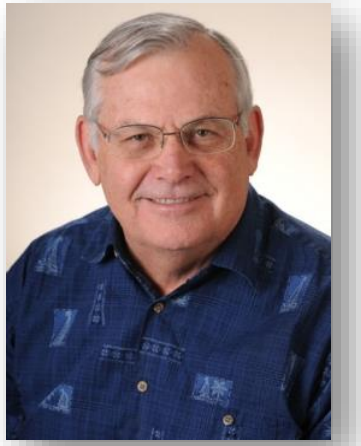

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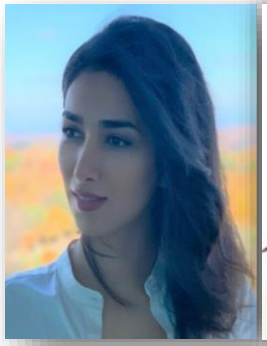

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Miguel Campos

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Mingze Li

The Need

WASHINGTON, DC
NLIHC released today its annual report

The Gap: A Shortage of Affordable Homes

National shortage of 7 million
affordable and available rental homes
for extremely low-income renters

those with incomes at or below the poverty level or 30% of area median income (AMI)

The US is in need of roughly
3.8 million to 5.5 million housing units.

Building more homes for
low- and moderate-income families
and first-time homebuyers,
and equipping these families
with reliable and affordable financing tools
so they can compete to buy these homes,
is essential if we're to solve the nation's
affordable homeownership crisis.

Opinion: How we can solve the nation's affordable housing crisis - CNN

Modular Construction as a Strategy

1900s

Augustine Taylor, a builder in Chicago, devised the balloon-frame method, enabling walls to be built offsite, then transported to the intended construction site, for speedy assembly.

The Rise of Catalog H

Between 1908 and 19

more than 500,000 pr

straight to consumers.

than two-thirds of con

still exist throughout th

A Brief History of Modular Con

Katerra was a startup founded in 2015 trying to become the Salesforce of construction. Its goal was to be a one-stop-shop, vertically integrated, construction project management company. The startup was trying to disrupt its $12T industry by implementing modern tech that was supp

construction proje

over its lifetime …

were told that the

paying severance

How Did Katerra Go From

So, when we look at Katerra's model and what they were trying to achieve, I think it was a whole bunch of talented people moving in the right direction, but from a business model perspective, they were really trying to boil the ocean. They were doing everything at once. And they had thousands of employees in a dozen countries. We are very focused on multifamily high density modular construction, and we already do it.

Modular builder CEO: 'Katerra's failure was spectacular' | Construction Dive

Partners In a Transformative Endeavor

https://mitekmodular.com/

Our Role

Focus on logistics
From the receipt
of construction materials
to the delivery of modules
to the erection site

Develop appropriate production facilities design processes including all aspects of logistics.

Validate designs through high-fidelity discrete event simulations and virtual reality visualizations.

Systems Engineering Approach

Research Goals

Transform
design and development
of off-site manufacturing
for cheaper , faster, safe & sustainable
distributed modular construction

Integrate digital connectivity,
componentization,
and off-site manufacturing

Development Stakeholders

Modular Design & Specification Team

Construction Process Definition Team

Facility & Logistics Design Team

Operational Control Development Team

Design Validation Team

Product

Process

Resources

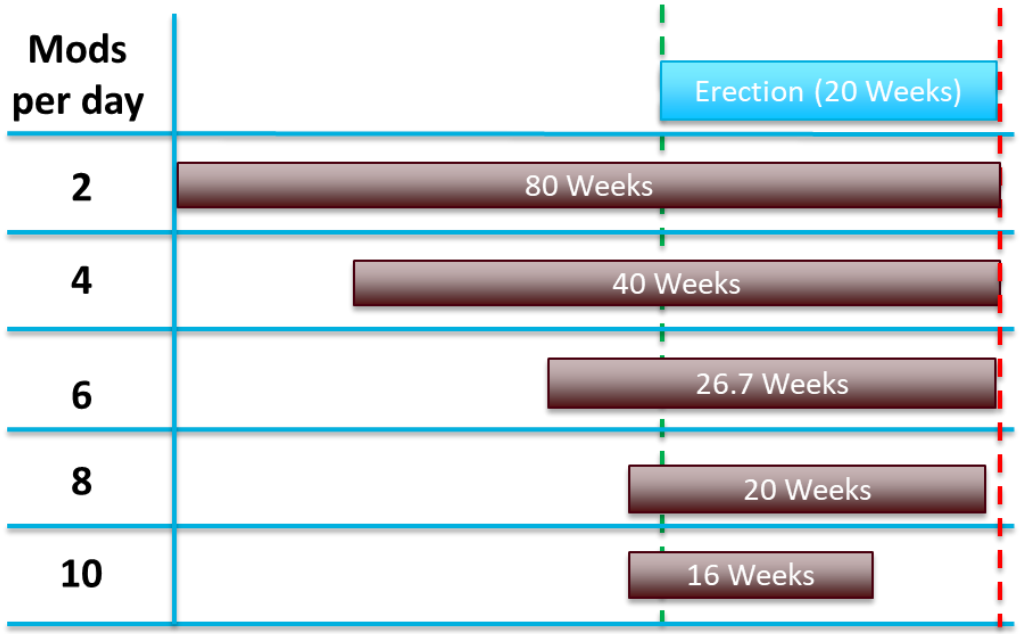
Operations Management

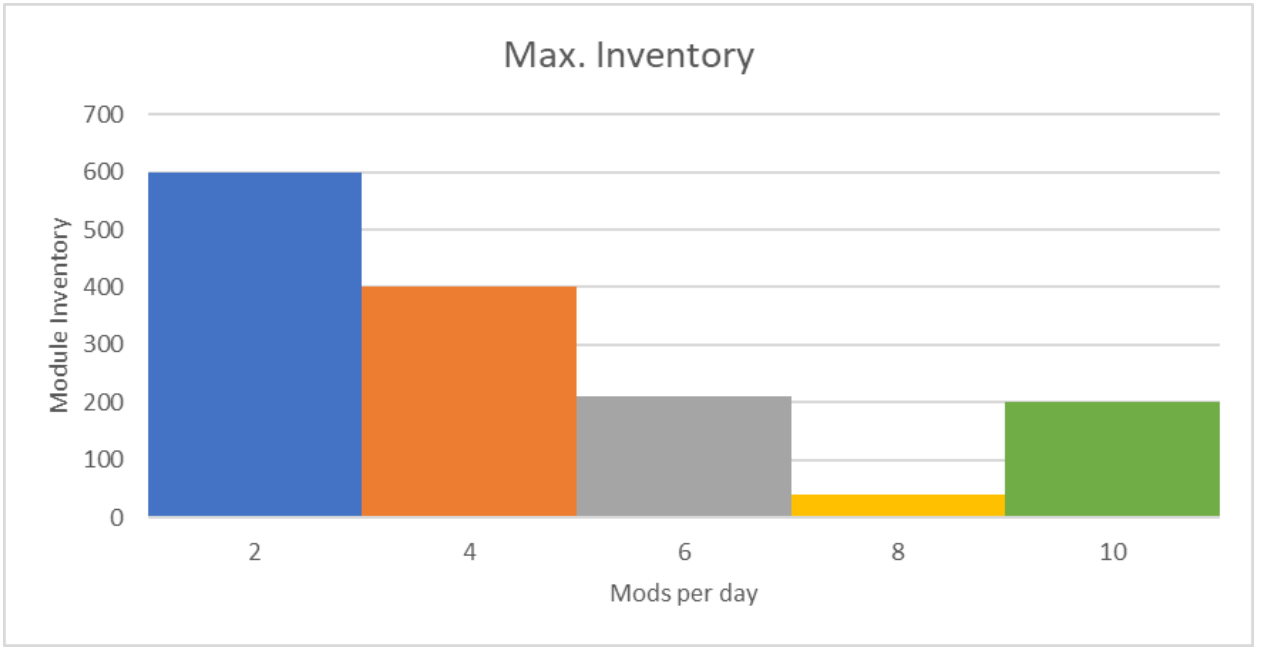
System Validation

Takt Time Driven Production and Inventory

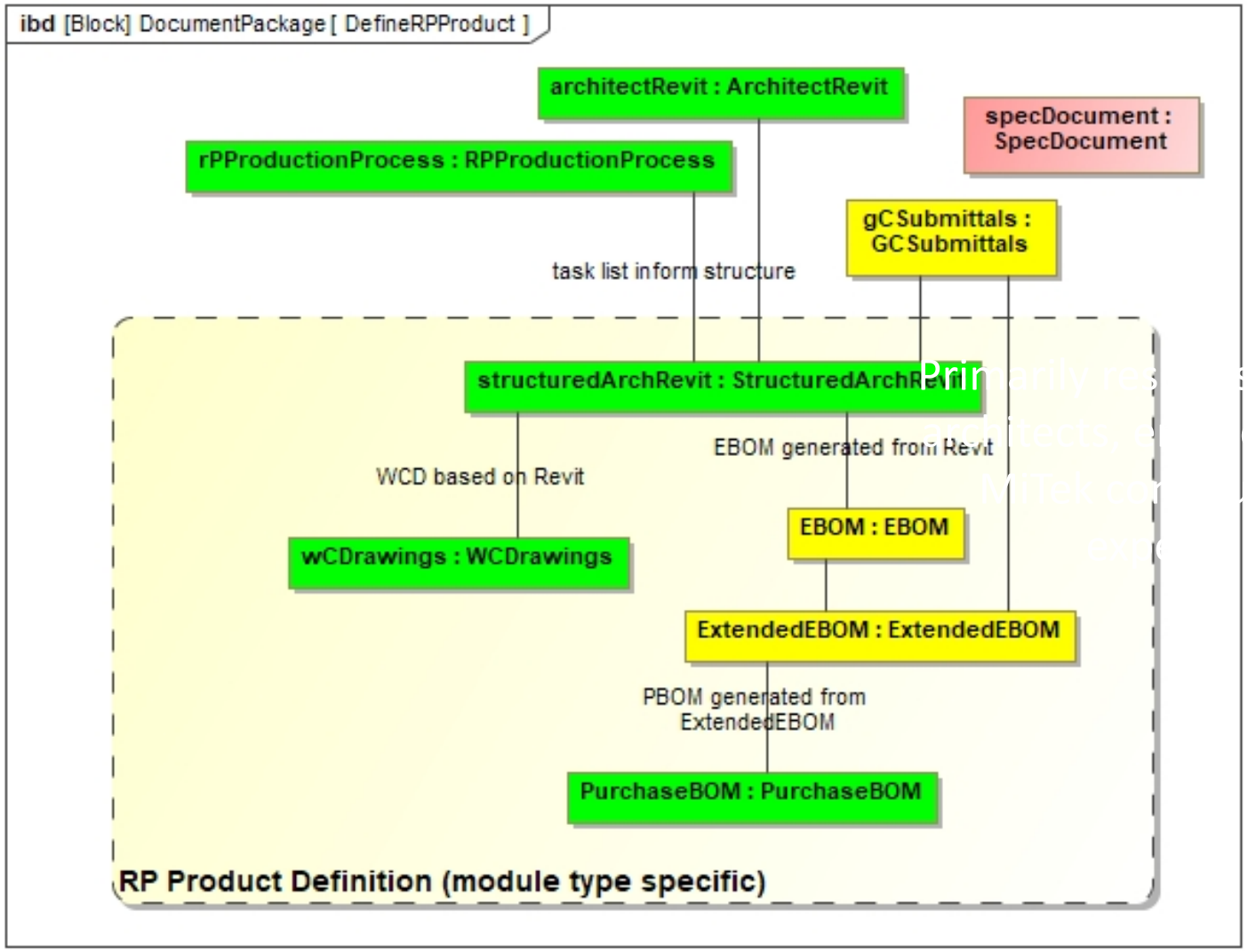
Item	Value	Units
Total project size	800	modules
Time before erecting (weeks)	12	weeks
Time for erection (weeks)	20	weeks
PUP Workdays	5	Days
Hours per work day	8	Hours
Erection work days	7	Days

Modules a day	Time before erecting (weeks)	Production time (weeks)	Takt Time	Max. Mod Inventory at Erection Start
2	60	80	4	600
4	20	40	2	400
6	7	26.7	1.3	210
8	1	20	1	40
10	1	16	0.8	200

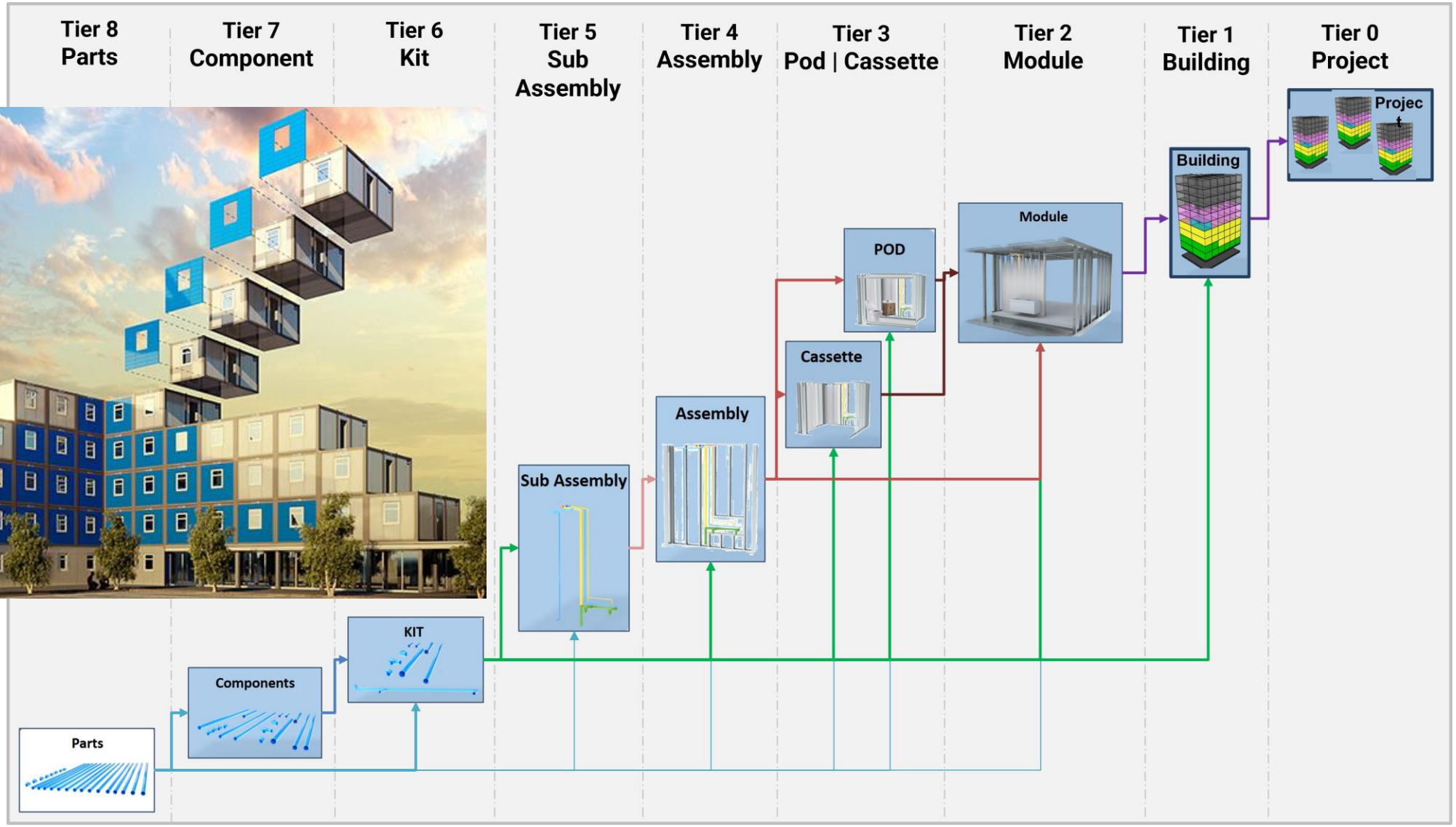




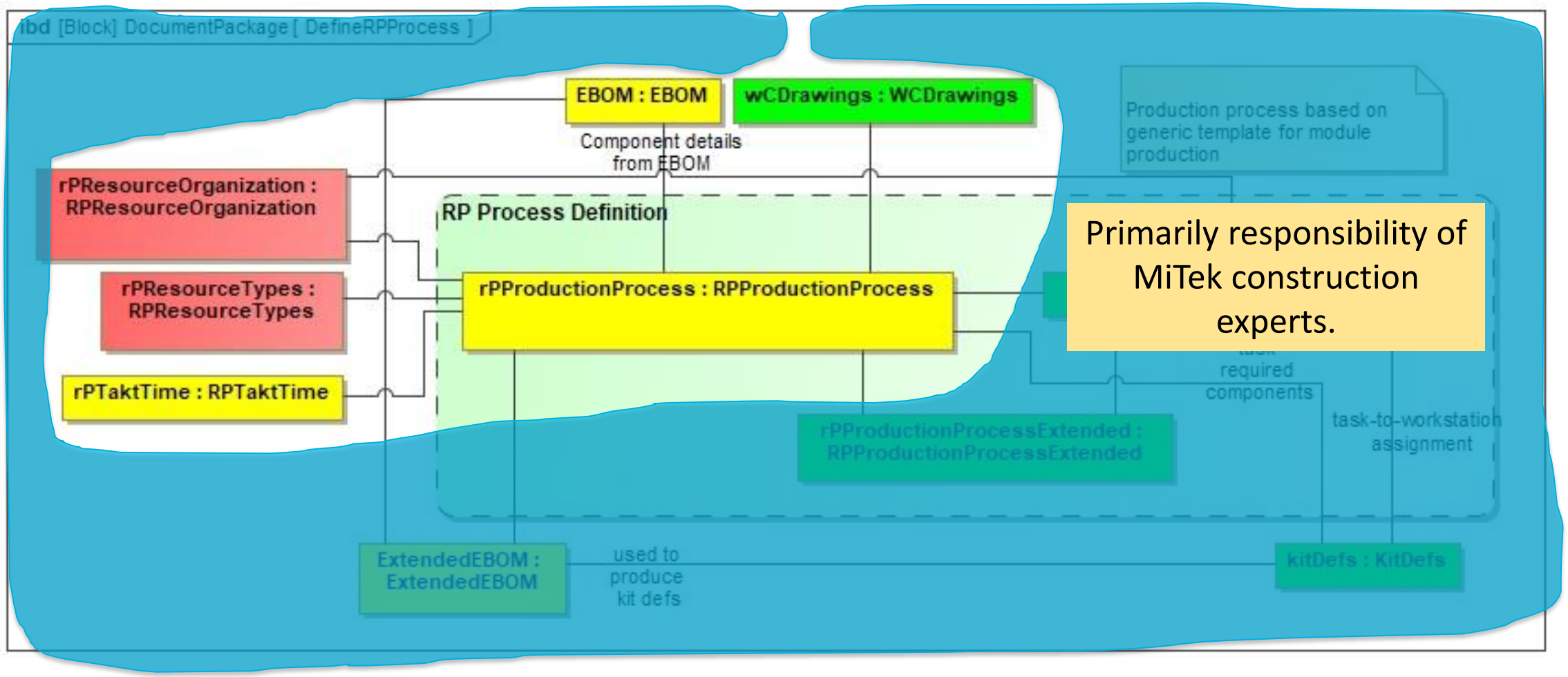
Defining the Product



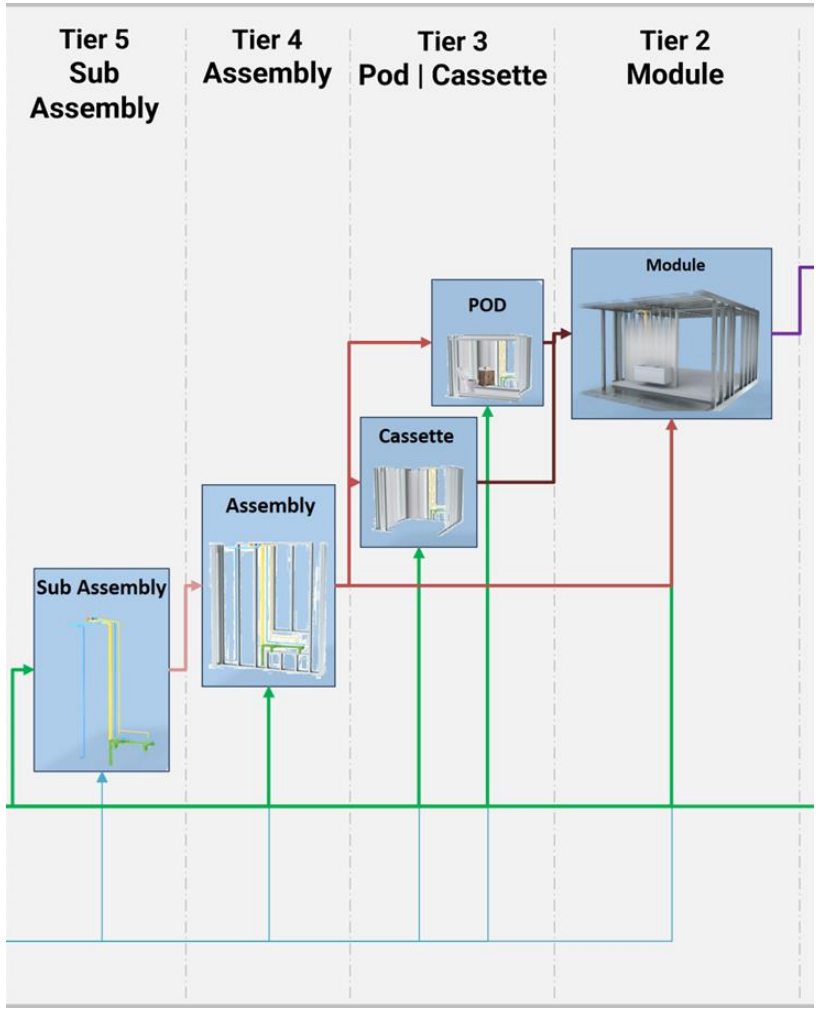
Tiered Product Model



Defining the Basic Construction Processes



Factory Functional Requirements



Functional requirements correspond to product structure and include:

- Preassembly center
- Floors center
- Mateline walls center
- Interior partitions center
- Subceilings center
- Ceilings center
- Volumetric assembly center
- Finishing center

POD example:
a “wet” portion of a Module

Logical Organization

- **How many workstations in each center?**
  - Allocate tasks from construction process to workstations to conform to takt time and “balance” workload at workstations

- **Required information**
  - Extended Bill of Materials - EBOM
  - Construction process:
    - tasks with precedence relationships , trade assignment, & tooling requirements

Rapid Plant Capacity Model

Product Model

Process model

Tasks to assemble products and their relationship

Demand model

Throughput: 1 module per hour

Organization model

Moving assembly line + Fixed stations;
Product-centric organization

Resource Model

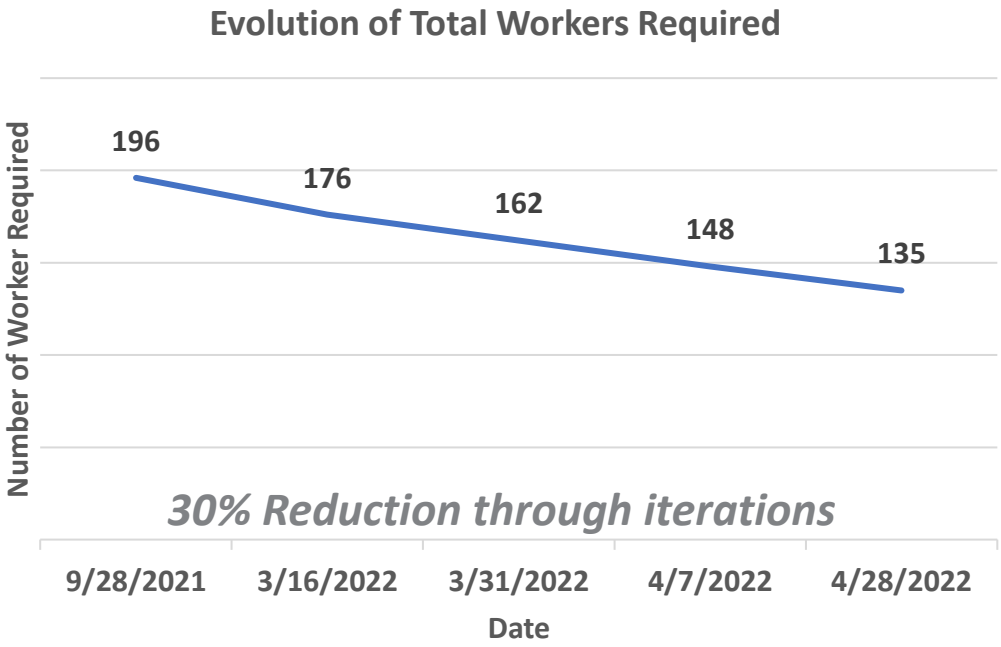
- Line Balancing
  - How many stations (equipment)?
- Labor Scheduling
  - How many workers?
  - What's the schedule of workers?

Input data from MiTek

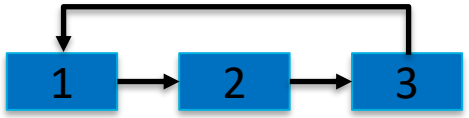
Assumptions

Work Product

1st set of tasks are done in 1st station,
2nd set of tasks are done in 2nd station,
…
After 1 takt time, all modules move to next station



Inter-Station Worker Movement

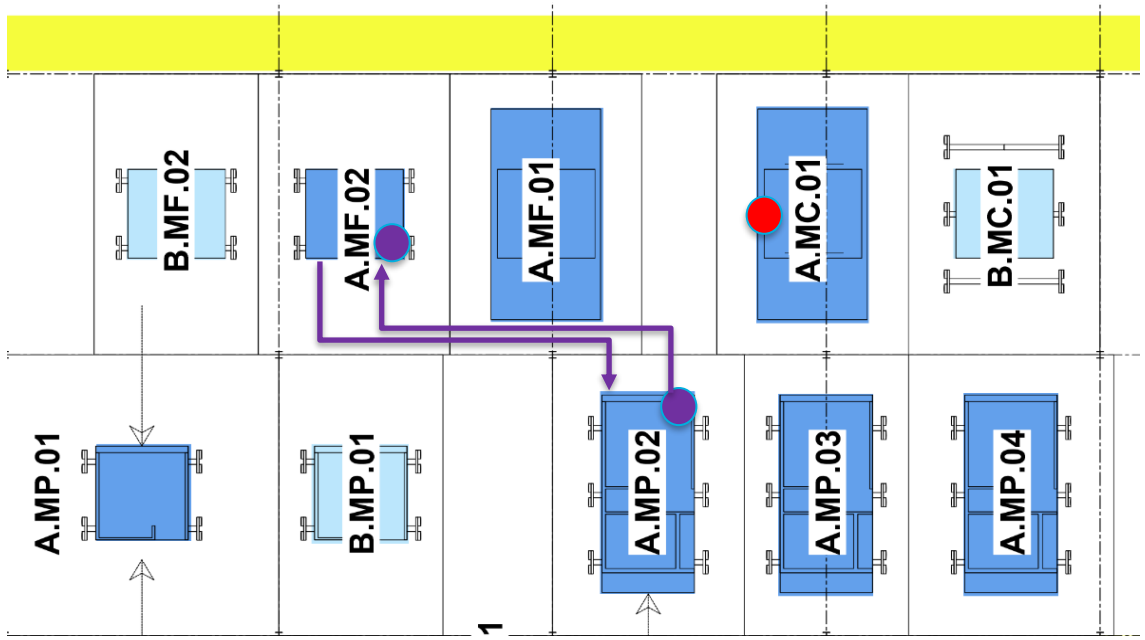


Worker's movement among 3 stations within 1 takt time

Why allow workers to move:

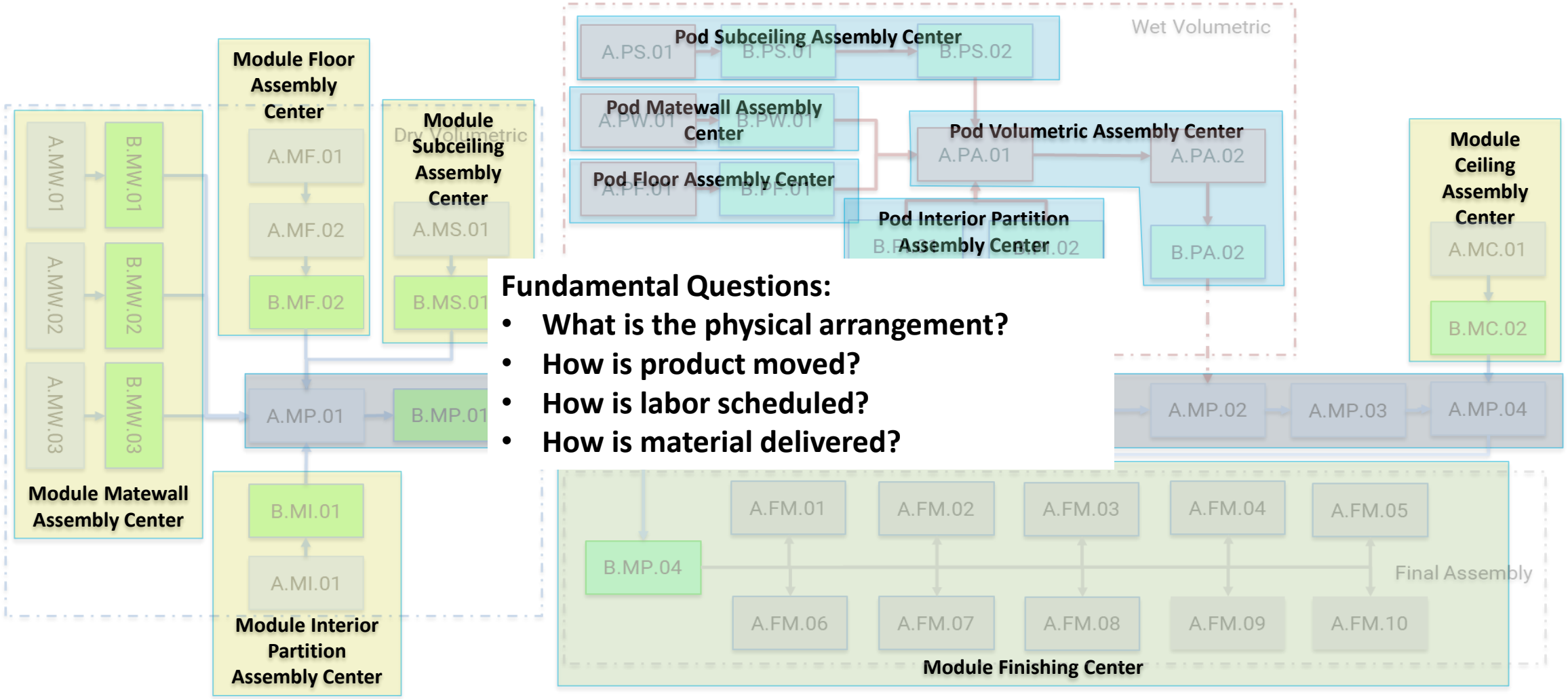
1. Allowing some workers to move ≠ Forcing all workers to move
2. Some teams can stay at same station all the time
3. Fewer workers required, better utilization: **276 (static) vs 135 (moving)**
4. Except for inspectors and supervisors, workers can work up to 3 stations

Large-scale discrete optimization solved using Gurobi™



- Team 14 (frame carpenter) stays at station A.MC.01 (ceiling)
- Team 10 (frame carpenter) works at station A.MP.02 (connecting subceiling) for 20min, then go to A.MF.02 (setting up floor), then return

Logical-to-Physical Model



Fundamental Questions:

- **What is the physical arrangement?**
- **How is product moved?**
- **How is labor scheduled?**
- **How is material delivered?**

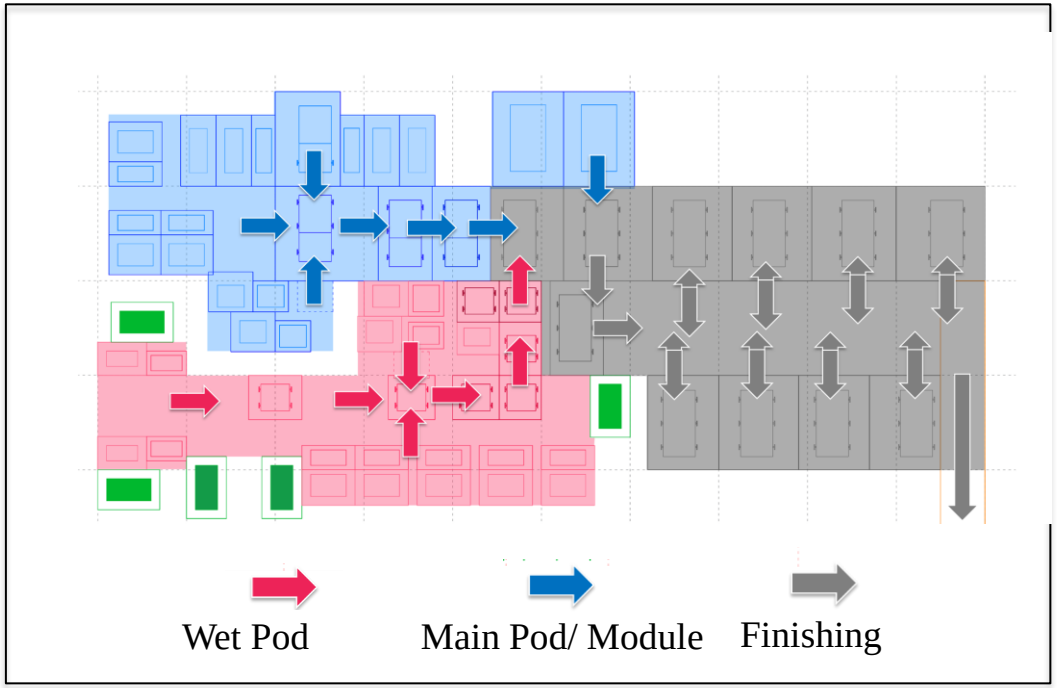
Modular Layout Design of Factory

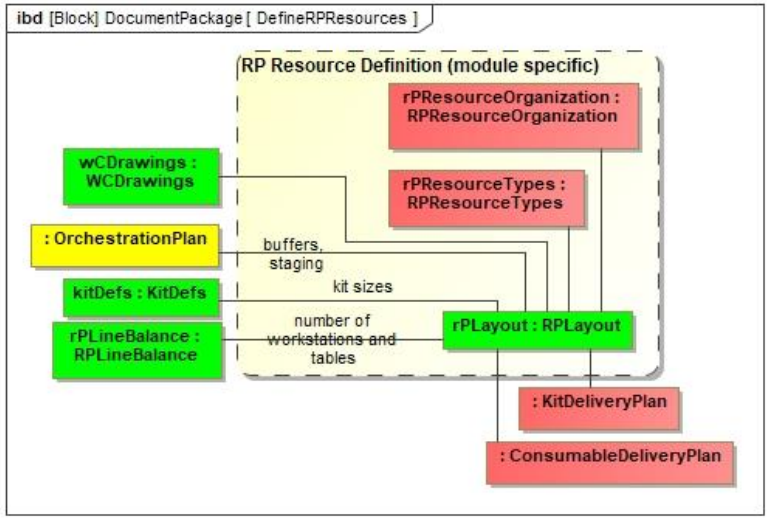
Goals:

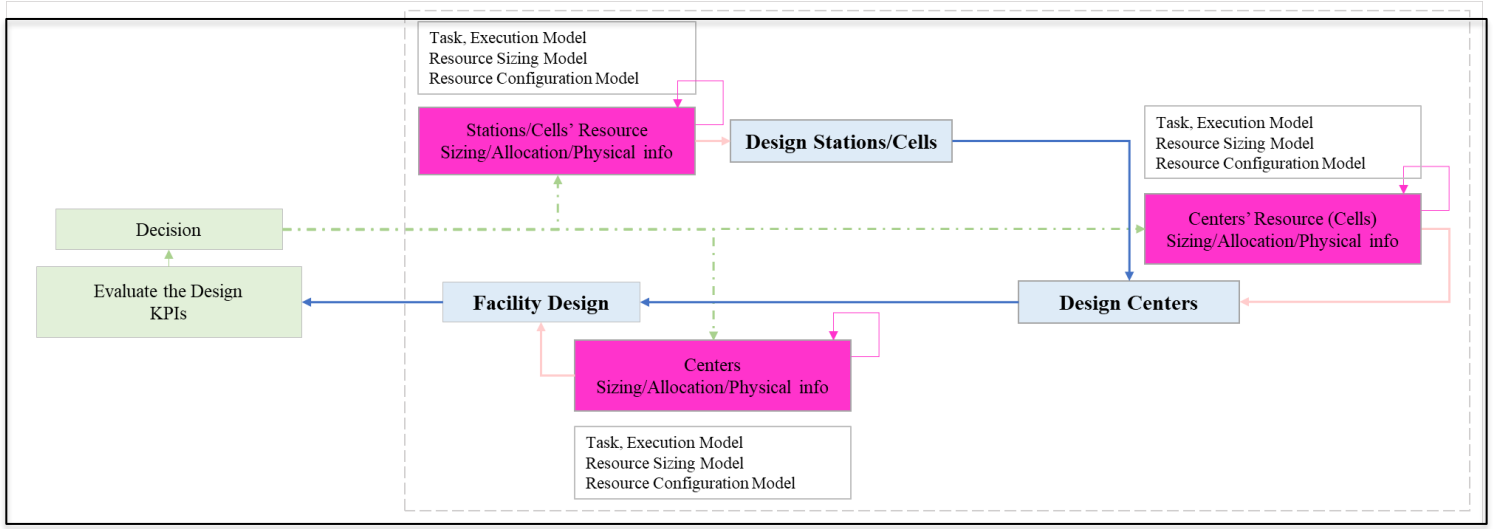
- **Transform** MiTek's original facility design
- Emphasis on the benefit of **modularity** and **mobility**
- **Flexibility** and **adaptability** of the layouts to the different number of machines and stations with minimal efforts to relocation and redesign.
- **Grid-based** layouts using predefined space blocks.
- Proof-of-Concept and evaluate in the Simulation Model.

Approach

- Standard-Size Modular Stations/Resources using WCD, Product model, & Resource Type
- Resource configuration using the Proximity Model
- Resource sizing using Line Balancing/Orchestration Plan



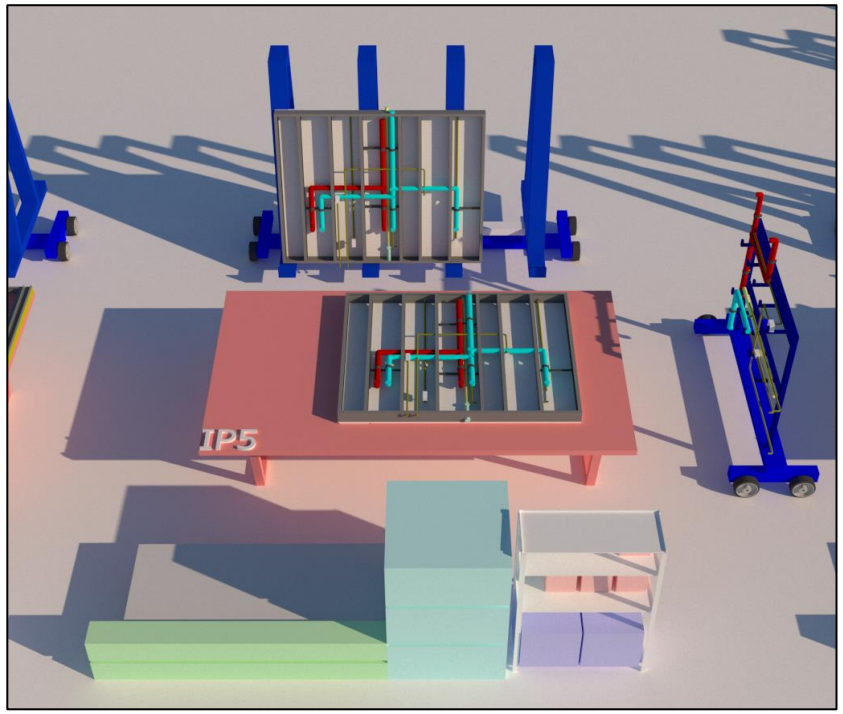


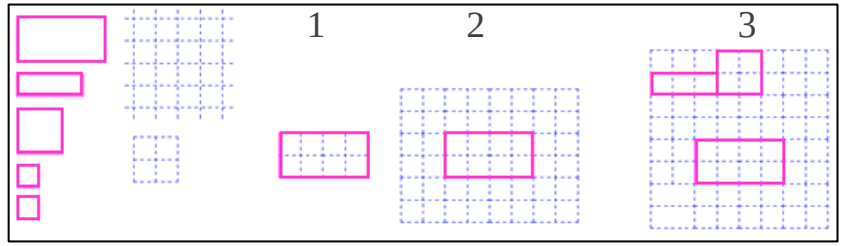


Factory Workstation/Center Design

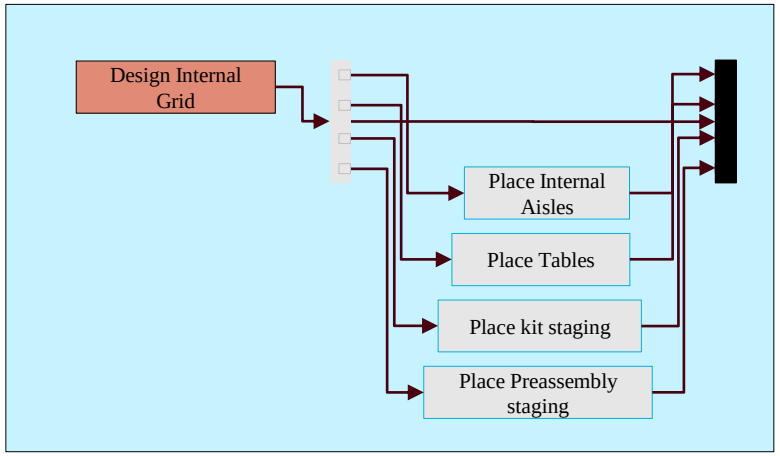
Approach
- Grid-based design
- Resource Sizing
- Resource Type
- Resource configuration

Modular Resources
- Table
- Kit rack
- Subassembly rack
- Workers

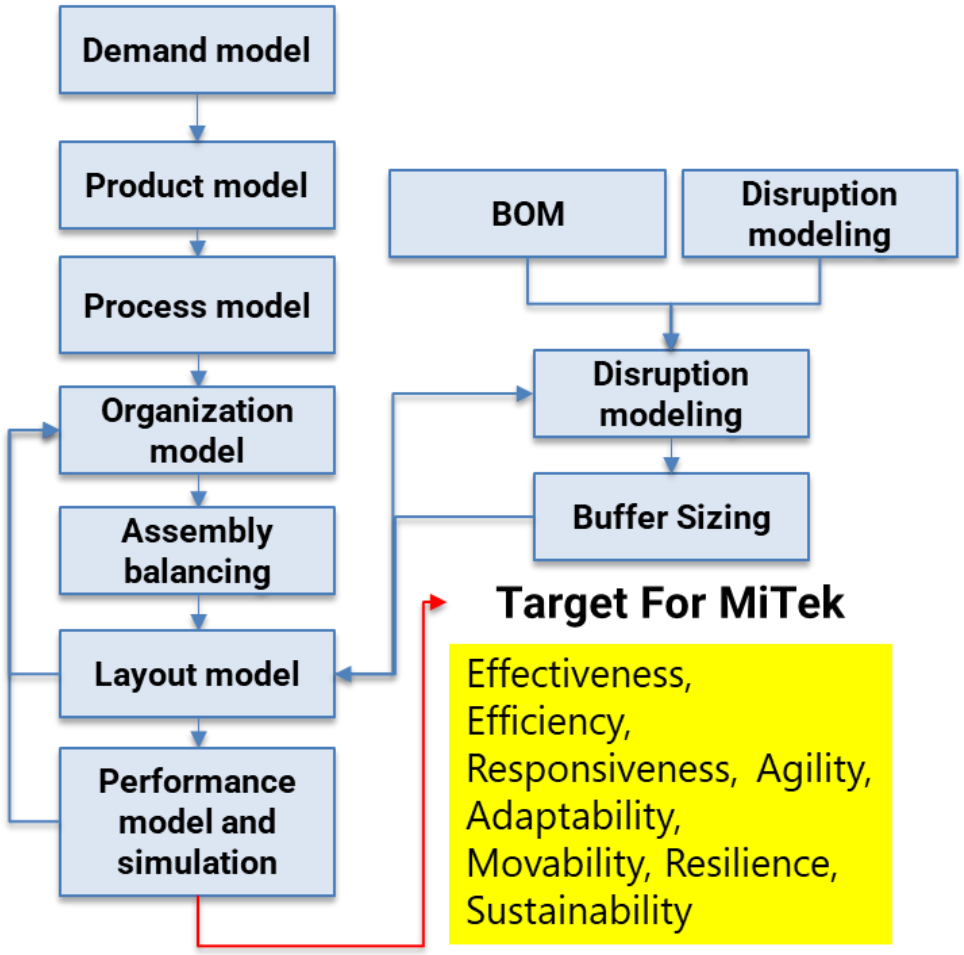


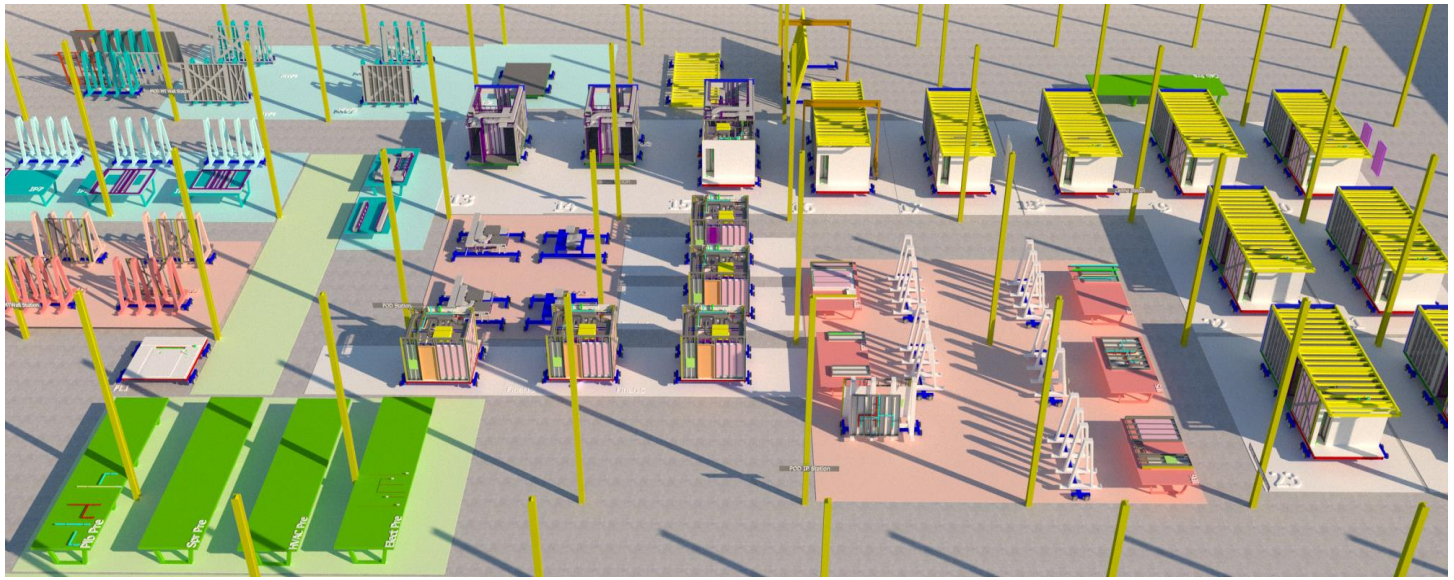


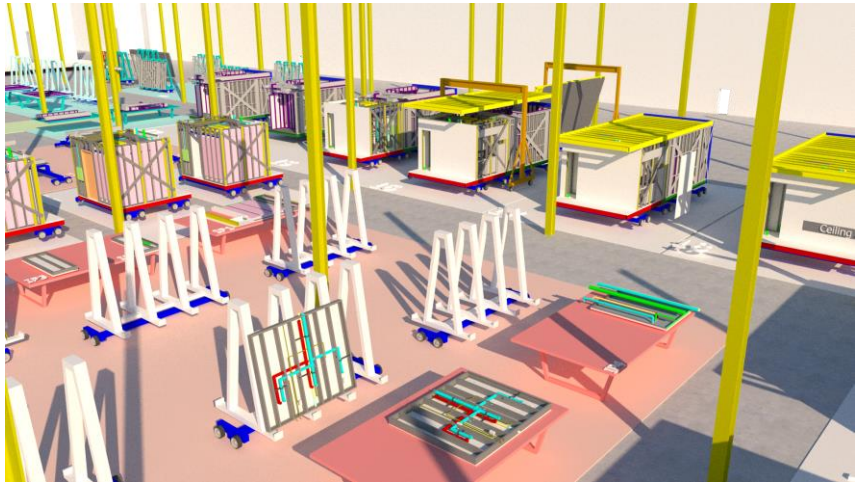
On the grid, in the right location



Factory Design Visualization







Takt Time Synchronization

mod 1								8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM
Station	takt time Ind	station code	Start in a T	End in a T	Start	End	Duration	300	360	420	480	540	600	660	720	780	840	900	960	1020	1080	1140	1200	1260	1320	1380	1440	1500	1560	1620	1680	1740	1800	1860	1920	1980	2040	2100	2160	2220	2280	2340	2400	2460	2520	2580	2640	2700	2760	2820	2880	2940
1	9	A.MF.01	28	60	508	540.0	32.0																																													
2	10	A.MF.02	8	54	548	594.0	46.0																																													
	11	B.MF.02	0	60	600	660.0	60.0																																												
3	10	A.MI.01	0	57	540	597.0	57.0																																												
	11	B.MI.01	0	60	600	660.0	60.0																																											
4	10	A.MW.01	0	51	540	591.0	51.0																																											
	11	B.MW.01	0	60	600	660.0	60.0																																											
5	10	A.MW.02	0	59	540	599.0	59.0																																											
	11	B.MW.02	0	60	600	660.0	60.0																																											
6	10	A.MW.03	0	58	540	598.0	58.0																																											
	11	B.MW.03	0	60	600	660.0	60.0																																											
7	10	A.MS.01	10	58	550	598.0	48.0																																											
	11	B.MS.01	0	60	600	660.0	60.0																																											
8	10	A.MC.01	0	54	540	594.0	54.0																																											
	11	B.MC.01	28	38	628	638.0	10.0																																											
9	12	A.MP.01	0	54	660	714.0	54.0																																											
	13	B.MP.01	0	60	720	780.0	60.0																																											
10	14	A.MP.02	0	25	780	805.0	25.0																																											
11	15	A.MP.03	0	50	840	890.0	50.0																																											
12	16	A.MP.04	0	50	900	950.0	50.0																																											
	17	B.MP.04	0	60	960	1020.0	60.0																																											
101	18	A.FM.01	0	38	1020	1058.0	38.0																																											
102	19	A.FM.02	0	38	1080	1118.0	38.0																																											
103	20	A.FM.03	0	39	1140	1179.0	39.0																																											
104	21	A.FM.04	0	38	1200	1238.0	38.0																																											
105	22	A.FM.05	0	51	1260	1311.0	51.0																																											
106	23	A.FM.06	0	51	1320	1371.0	51.0																																											
107	24	A.FM.07	0	56	1380	1436.0	56.0																																											
108	25	A.FM.08	0	31	1440	1471.0	31.0																																											
109	26	A.FM.09	21	31	1521	1531.0	10.0																																											
110	27	A.FM.10	0	53	1560	1613.0	53.0																																											
1	6	A.PF.01	5	112	305	412.0	107.0																																											
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2	6	A.PI.01	0	98	300	398.0	98.0																																											
	8	B.PI.01	0	120	420	540.0	120.0																																											
3	6	A.PI.02	6	102	306	402.0	96.0																																											
	8	B.PI.02	0	120	420	540.0	120.0																																											
4	6	A.PW.01	0	117	300	417.0	117.0																																											
	8	B.PW.01	0	120	420	540.0	120.0																																											
5	6	A.PS.01	0	117	300	417.0	117.0																																											
	8	B.PS.01	0	120	420	540.0	120.0																																											
7	10	A.PA.01	0	104	540	644.0	104.0																																											
8	12	A.PA.02	0	113	660	773.0	113.0																																											
	14	B.PA.02	0	120	780	900.0	120.0																																											

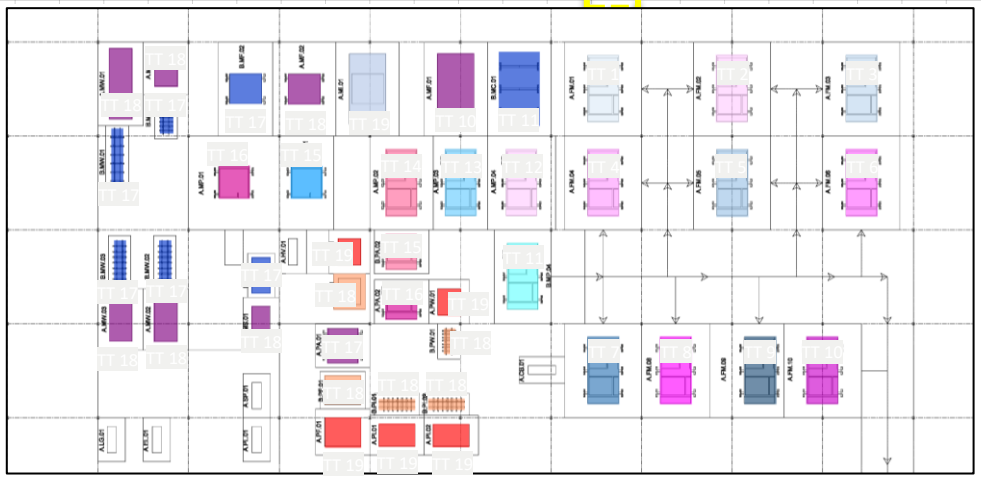
Main Pod

Finishing

Wet Pod

Wet Module

Dry Module



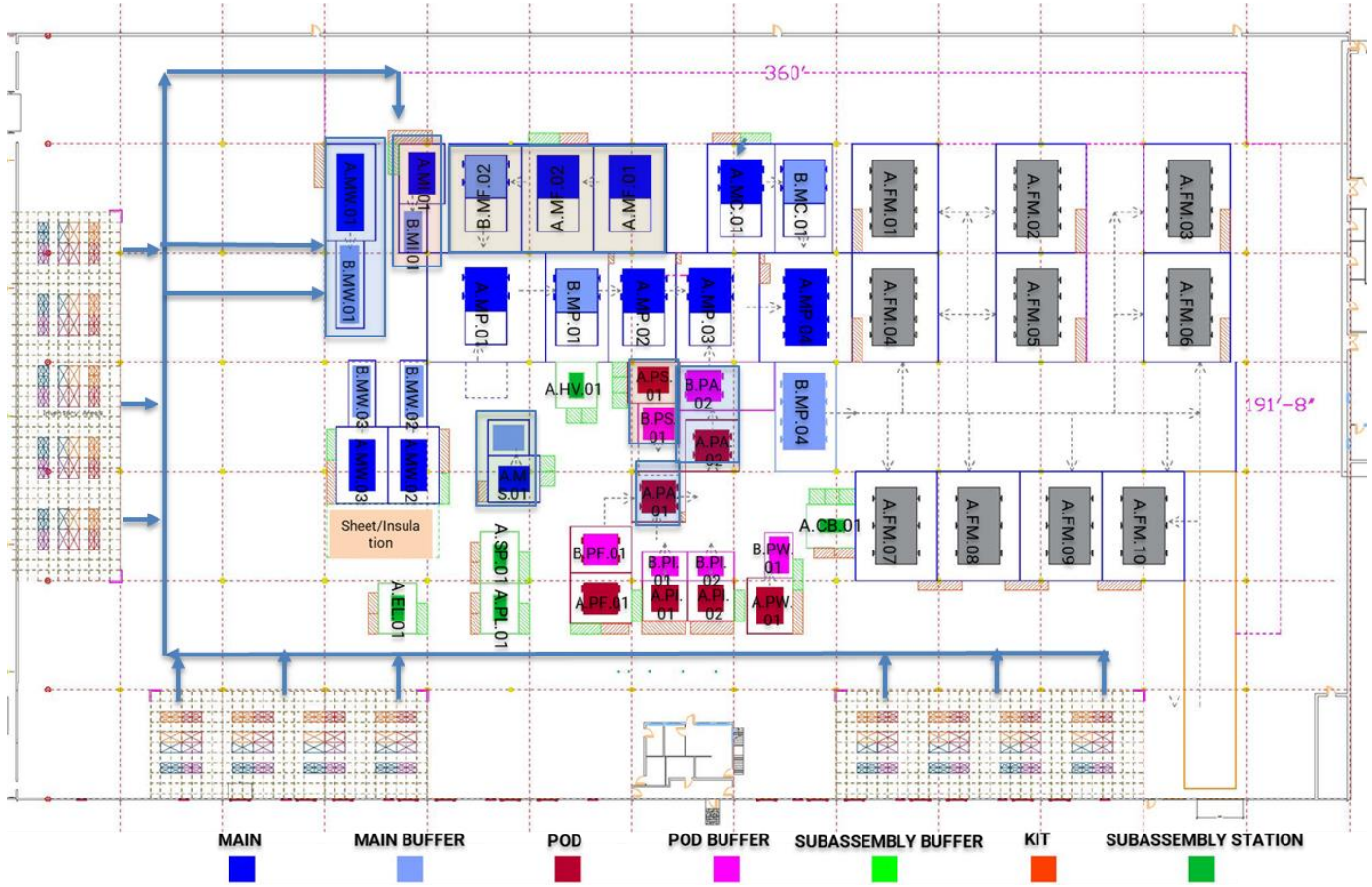
A.MF.01	Dry Mod 10
A.MF.02	Wet Mod 9
B.MF.02	Dry Mod 9
A.MI.01	Wet Mod 9
B.MI.01	Dry Mod 9
A.MW.01	Wet Mod 9
B.MW.01	Dry Mod 9
A.MW.02	Wet Mod 9
B.MW.02	Dry Mod 9
A.MW.03	Wet Mod 9
B.MW.03	Dry Mod 9
A.MS.01	Wet Mod 9
B.MS.01	Dry Mod 9
A.MC.01	Wet Mod 9
B.MC.01	Dry Mod 9
A.MP.01	Wet Mod 8
B.MP.01	Dry Mod 8
A.MP.02	Wet Mod 7
A.MP.03	Dry Mod 7
A.MP.04	Wet Mod 6
B.MP.04	Dry Mod 6
A.FM.10	Wet Mod 5
A.FM.09	Dry Mod 5
A.FM.08	Wet Mod 4
A.FM.07	Dry Mod 4
A.FM.06	Wet Mod 3
A.FM.05	Dry Mod 3
A.FM.04	Wet Mod 2
A.FM.03	Dry Mod 2
A.FM.02	Wet Mod 1
A.FM.01	Dry Mod 1
A.PF.01	Wet Mod 11
B.PF.01	Wet Mod 10
A.PI.01	Wet Mod 11
B.PI.01	Wet Mod 10
A.PI.02	Wet Mod 11
B.PI.02	Wet Mod 10
A.PW.01	Wet Mod 11
B.PW.01	Wet Mod 10
A.PS.01	Wet Mod 11
B.PS.01	Wet Mod 10
A.PA.01	Wet Mod 9
A.PA.02	Wet Mod 8
B.PA.02	Wet Mod 7

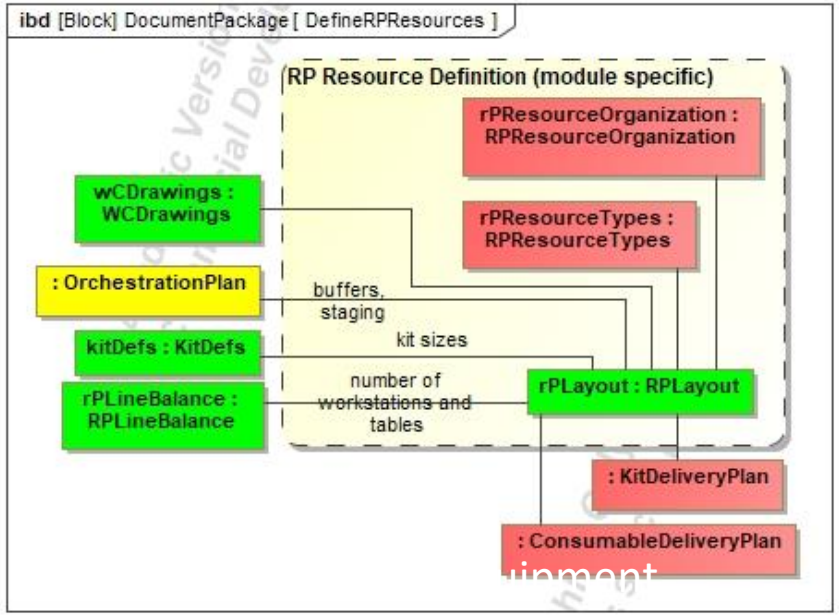
Factory Logistics Processes

Purpose:

Generate tasks for the movement of products and materials.

Storage, retrieval and delivery





Simulation-Based Factory Design Validation

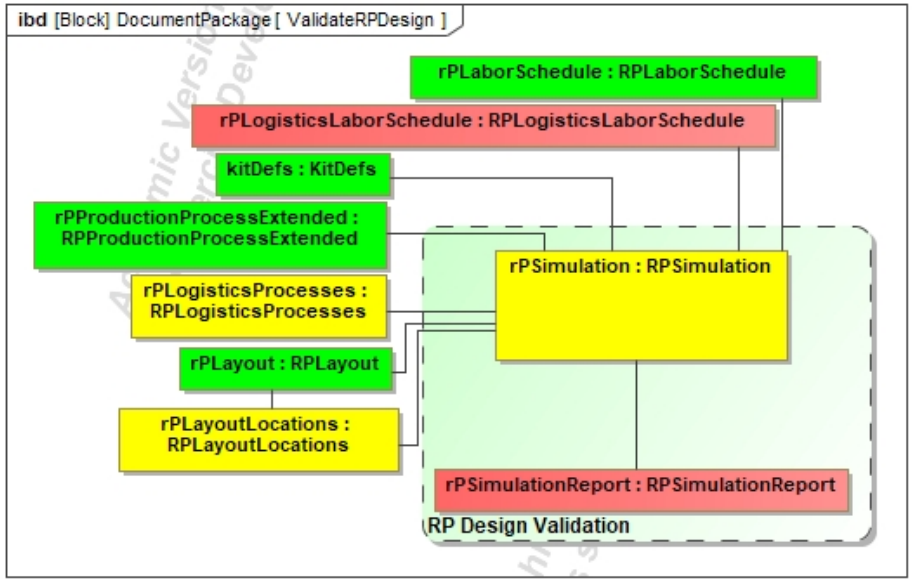
Purpose:

Assess the proposed system operation through simulation for identifying potential issues, improving the system design and operations and enabling real implementation.

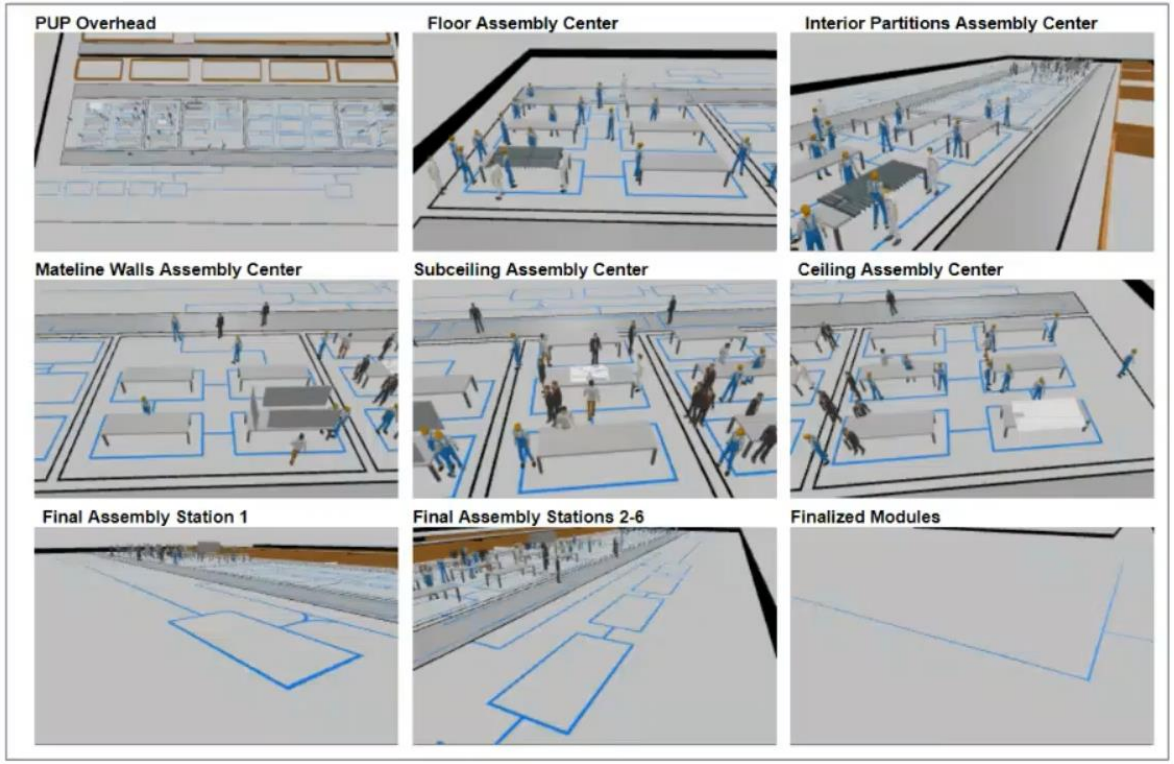
The validation allows informed data-based decision making and tracks KPIs for predicting system's performance.

Information Required:

Production Process, Logistics Process, Labor Schedule, Layout, Kit Definition, Production Program



High fidelity modelling



Progress Synthesis

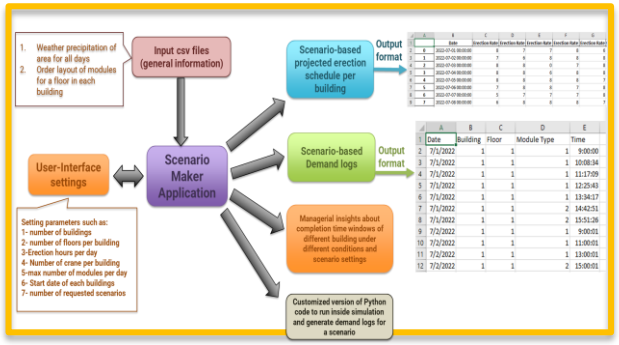
Georgia Tech
World-class expertise in modeling, design, analysis, planning & operation of supply chains, production & logistic systems & facilities

MiTek
World-class expertise in modular design and conventional construction

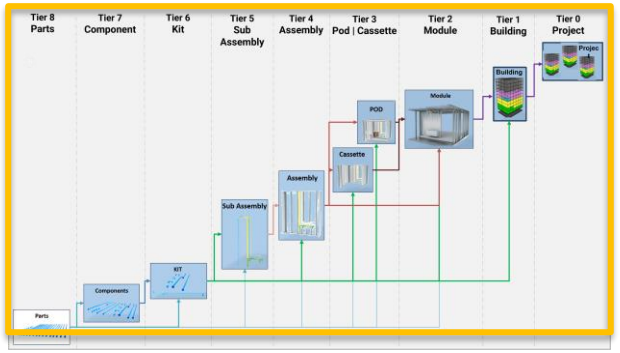
Partnership
Transforming modular construction toward high performance, scalability, resilience, sustainability & hyperconnectivity

- Speeding up the time to first project delivery
- Reducing risks
- Improving achievable capabilities & performance

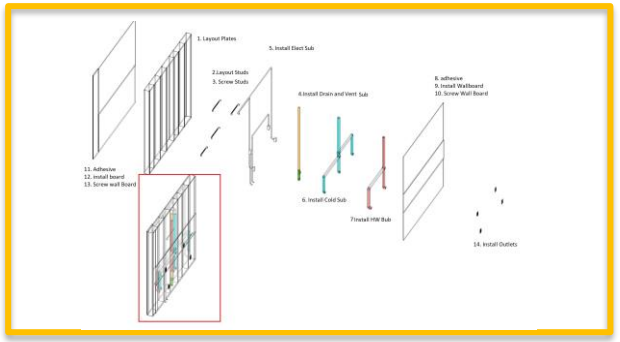
Demand & Project Modeling



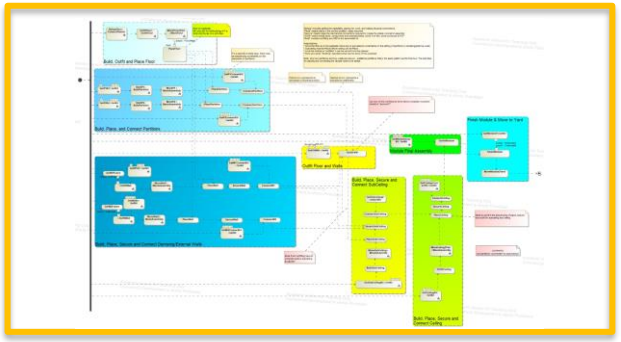
Product Design Modeling



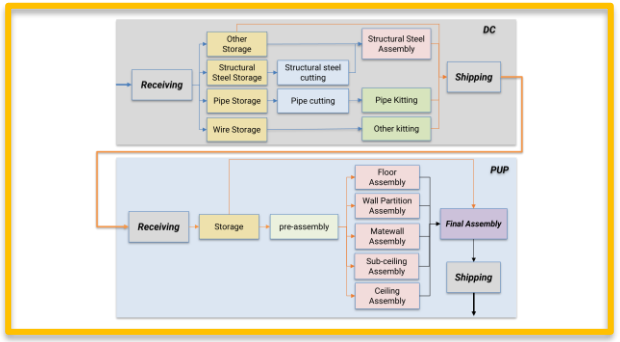
Manufacturing Product Modeling



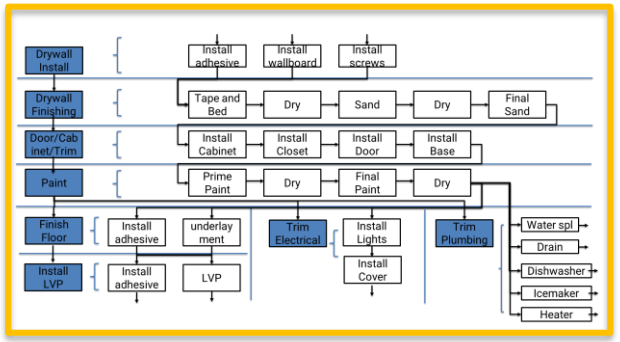
Production Process Modeling



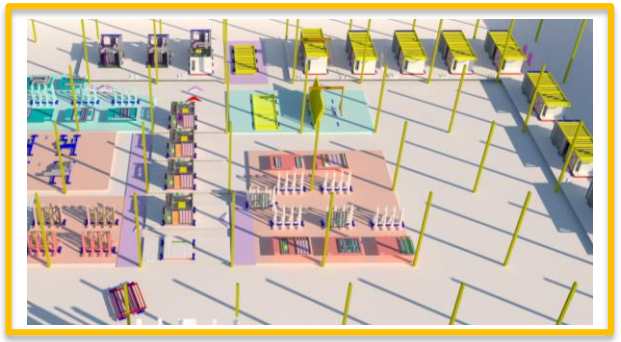
Network Organization Modeling



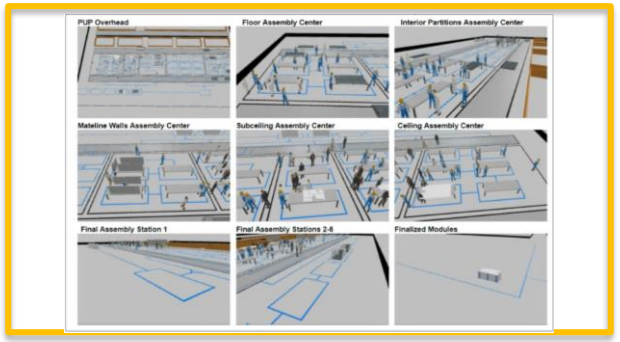
Capacity & Resource Modeling



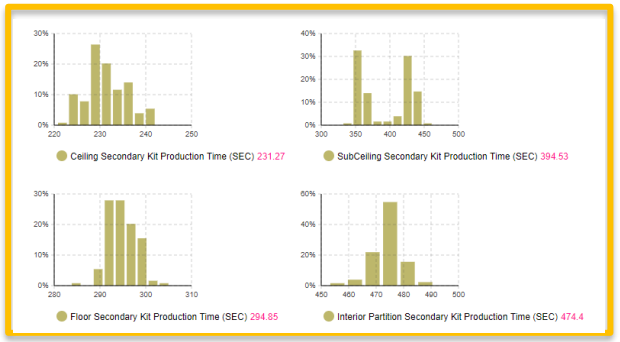
Layout Design Modeling



Simulation Modeling



Performance Modeling



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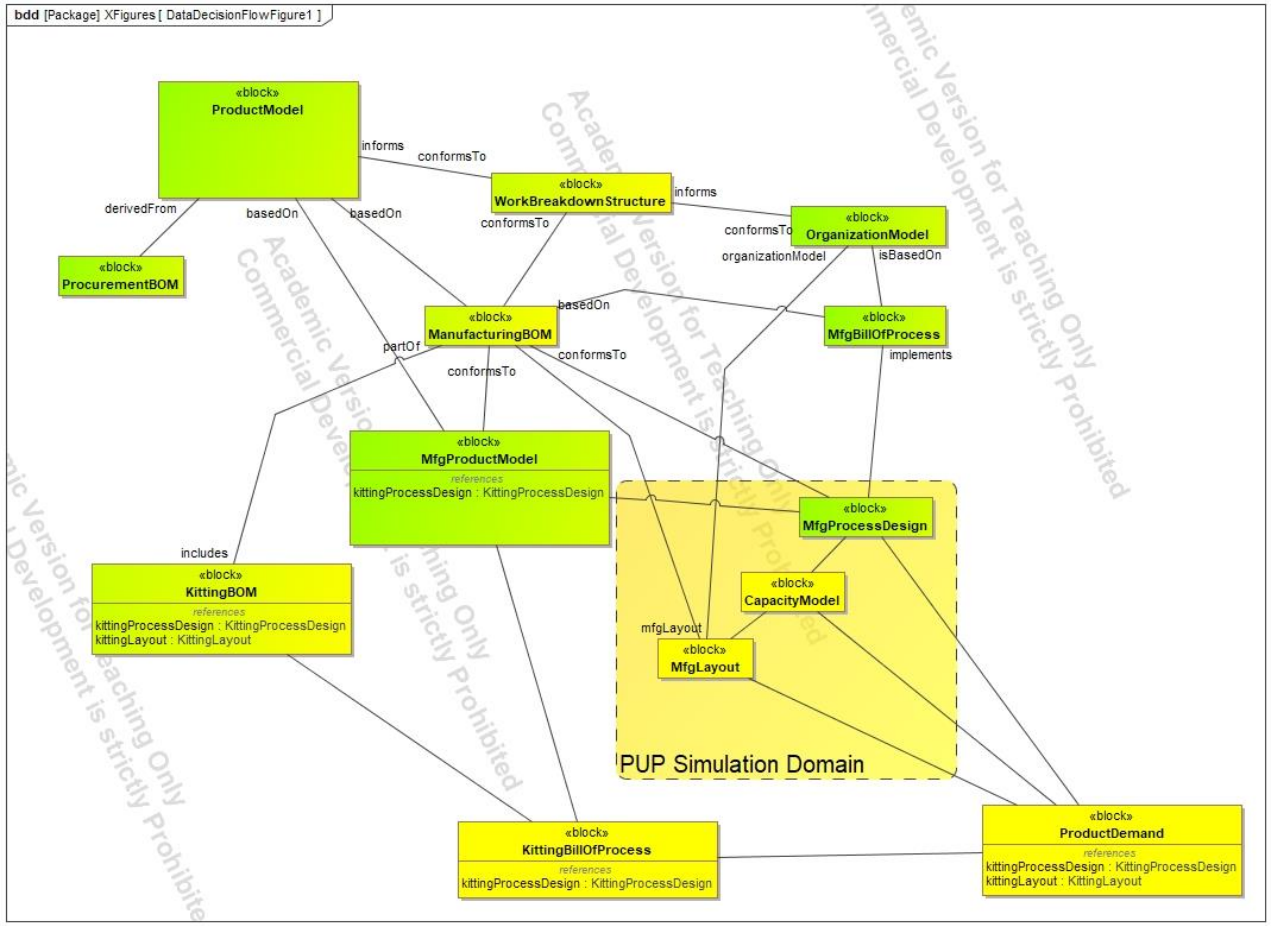
Design Process Integration



There are a lot of moving parts to this initiative

We are aware of and collaborating to address the need to identify, document, and standardize all the key data sources and computational processes, including version control

Phase II objective includes to largely automate the exchange of data and information between the various modeling tools developed to support design decision-making

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