DfMA Forum 2019| 1-2 October 2019
Providence, Rhode Island

DfMA in Building Design and Production: Uses and Abuses

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MONASH University

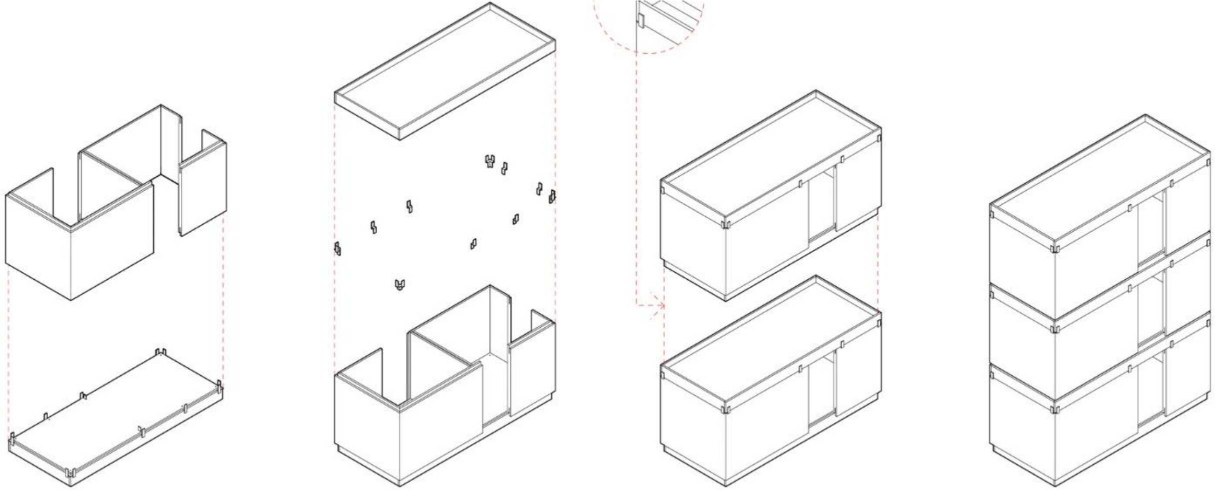
01

Who are we?

FBI Lab

applied research with industry partners Lendlease + DesignMake

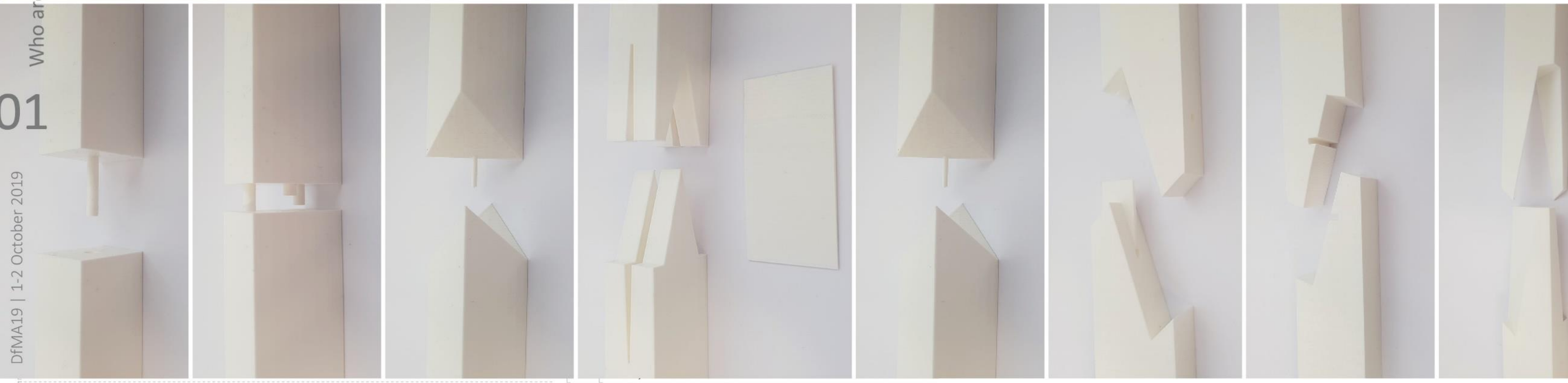
LEFT | International House facade, image sourced from https://www.geberit.com.au/know-how/reference-projects/international-house-barangaroo-nsw/
RIGHT | International house ceiling, image sourced from http://builtoffsite.com.au/issue-08/awards-rewards-future-wood/

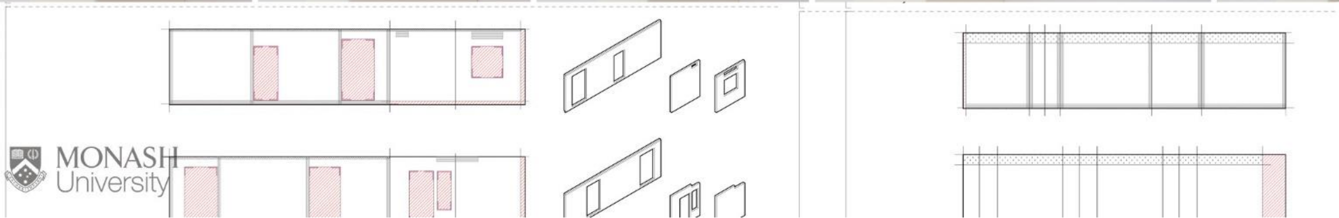


Who are we?

01

DfMA19 | 1-2 October 2019





design research methodology

MONASH University

Who are we?

01

26th JUNE | TUESDAY

27th JUNE | WEDNESDAY

28th JUNE | THURSDAY

29th JUNE | FRIDAY

2nd JULY | MONDAY

3rd JULY | TUESDAY

4th JULY | WEDNESDAY

5th JULY | THURSDAY

6th JULY | FRIDAY

9th JULY | MONDAY

10th JULY | TUESDAY

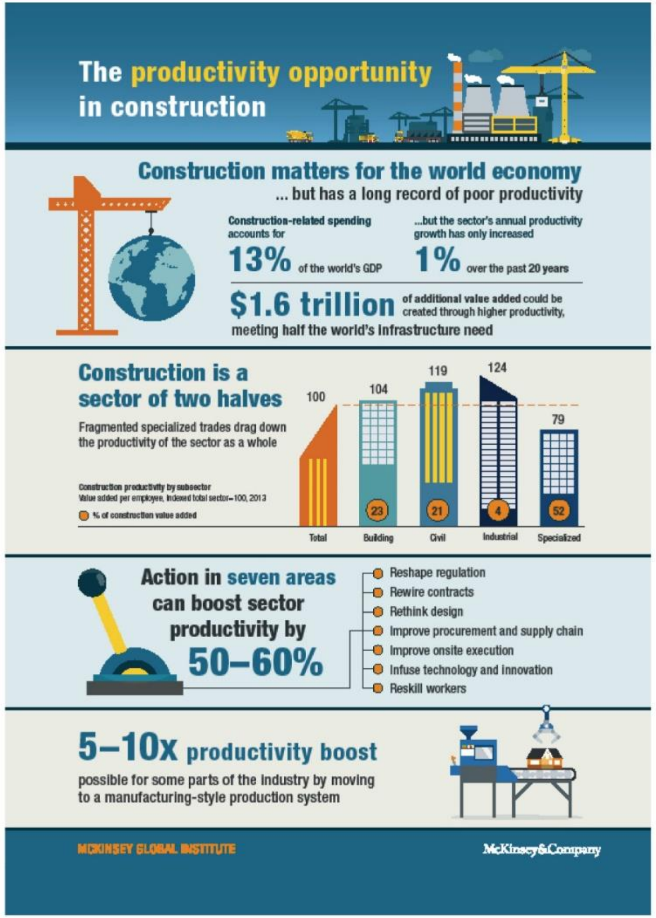
11th JULY | WEDNESDAY

building production time-lapse analysis

construction site field work

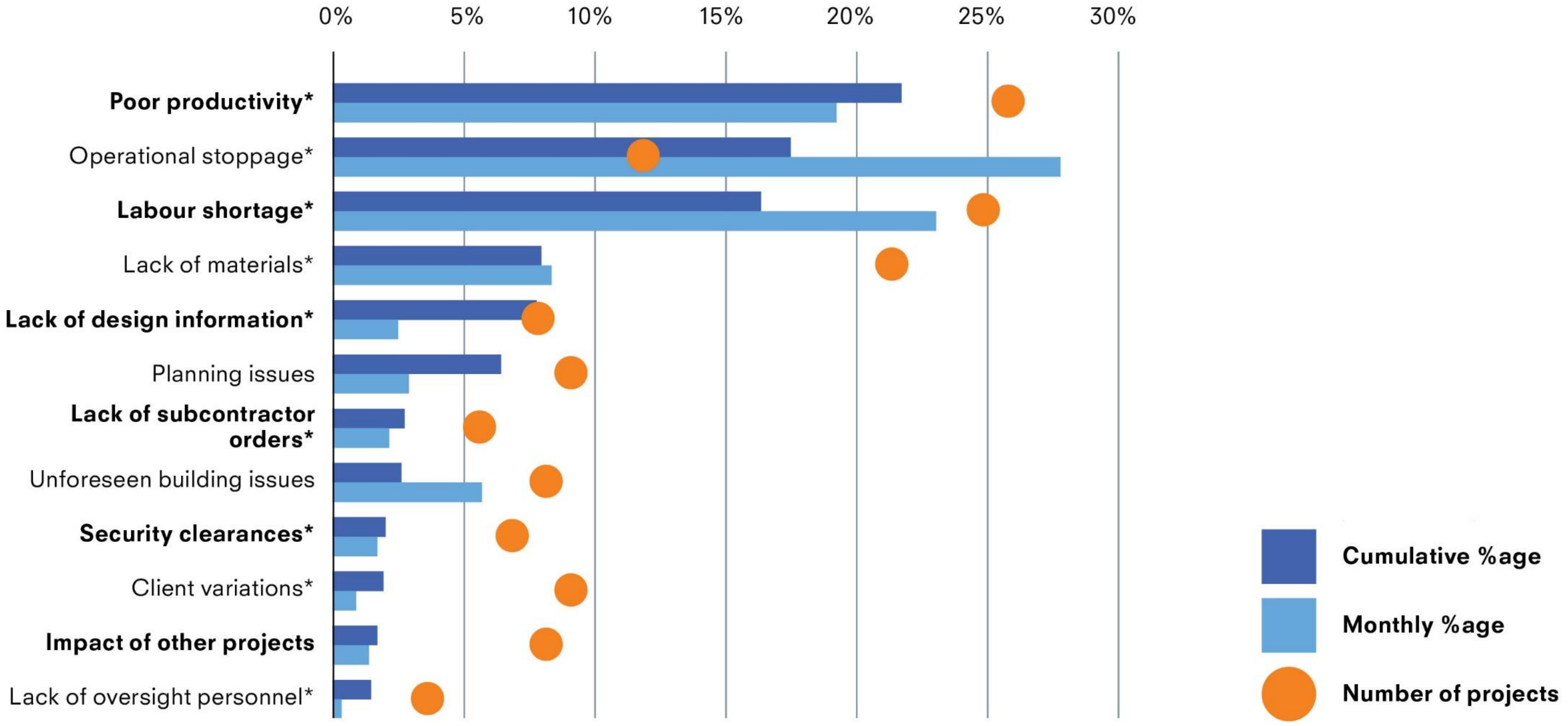
MONASH University

realities of construction



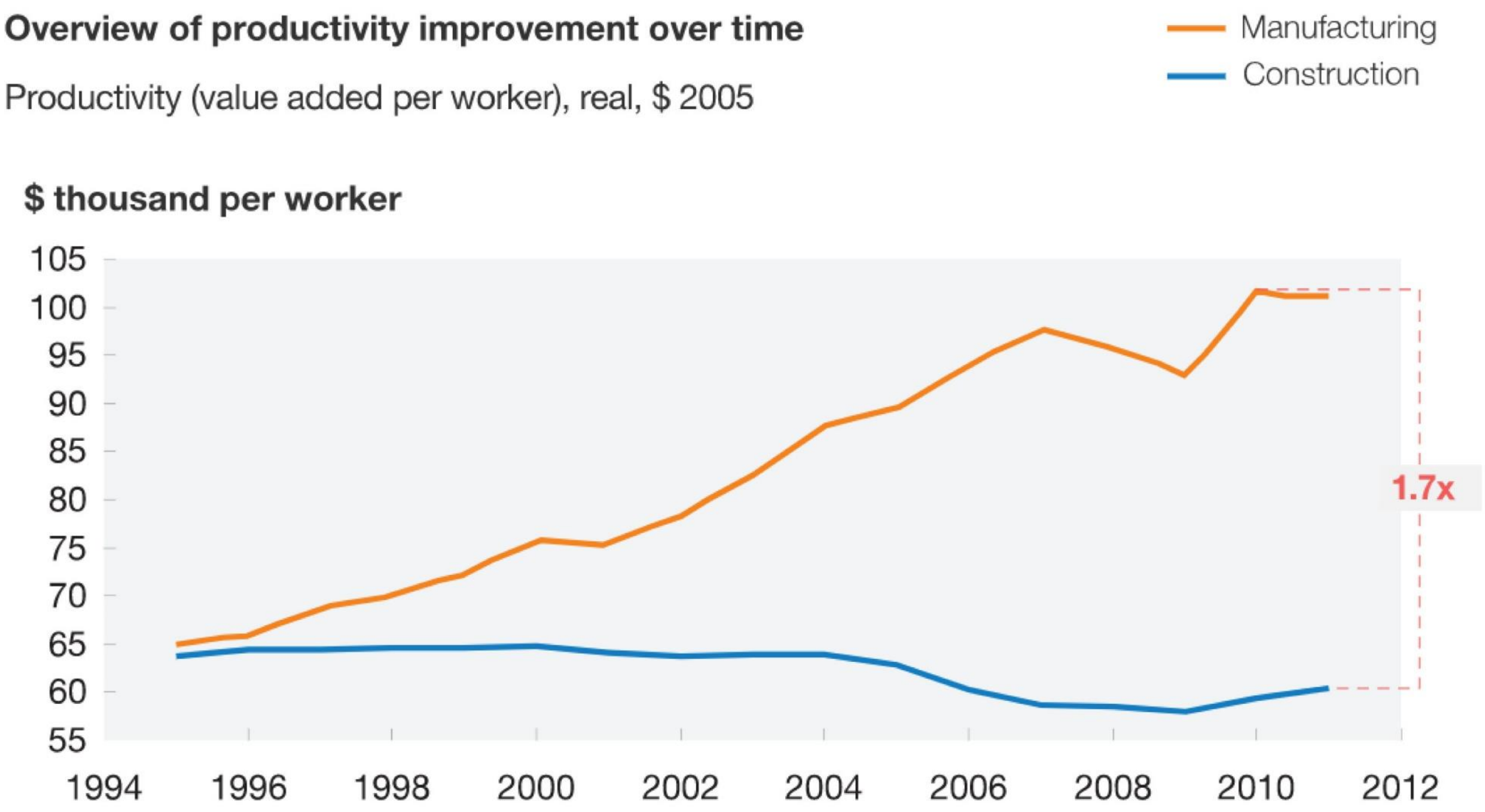
state of the industry

SOURCE | Barbosa et al., *Reinventing Construction: A Route to Higher Productivity,* (McKinsey & Company, 2017), accessed September 14, 2019, https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution.



reasons for project delays causing additional cost

SOURCE | *Delivery Platforms for Government Assets Creating a marketplace for manufactured spaces.* (Bryden Wood Technology Limited: 2017), 8-9.

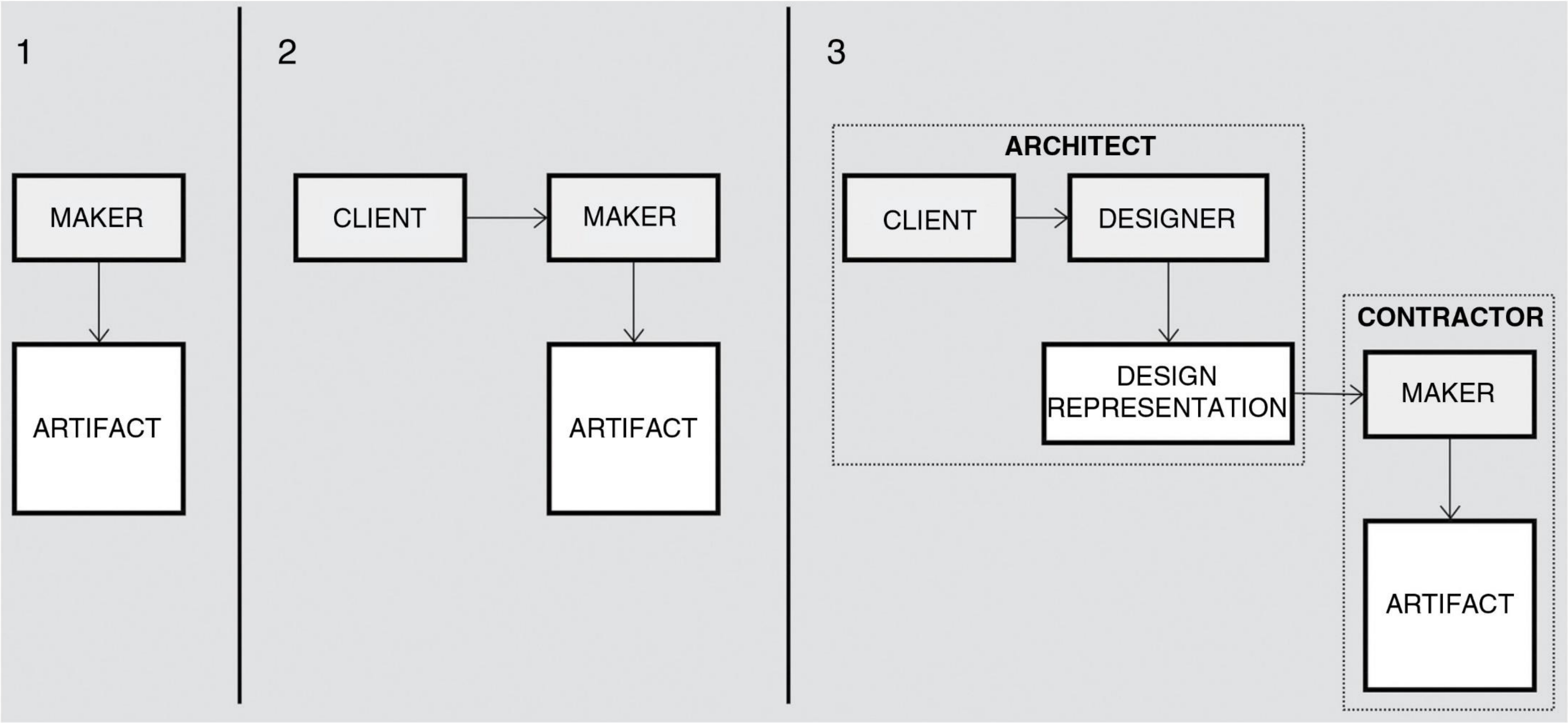


productivity comparison

SOURCE | Chart by McKinsey & Company, as found in Sriram Changali, Azam Mohammad, and Mark van Nieuwland, "The Construction Productivity Imperative", 2015, https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/the-construction-productivity-imperative

industrialised construction

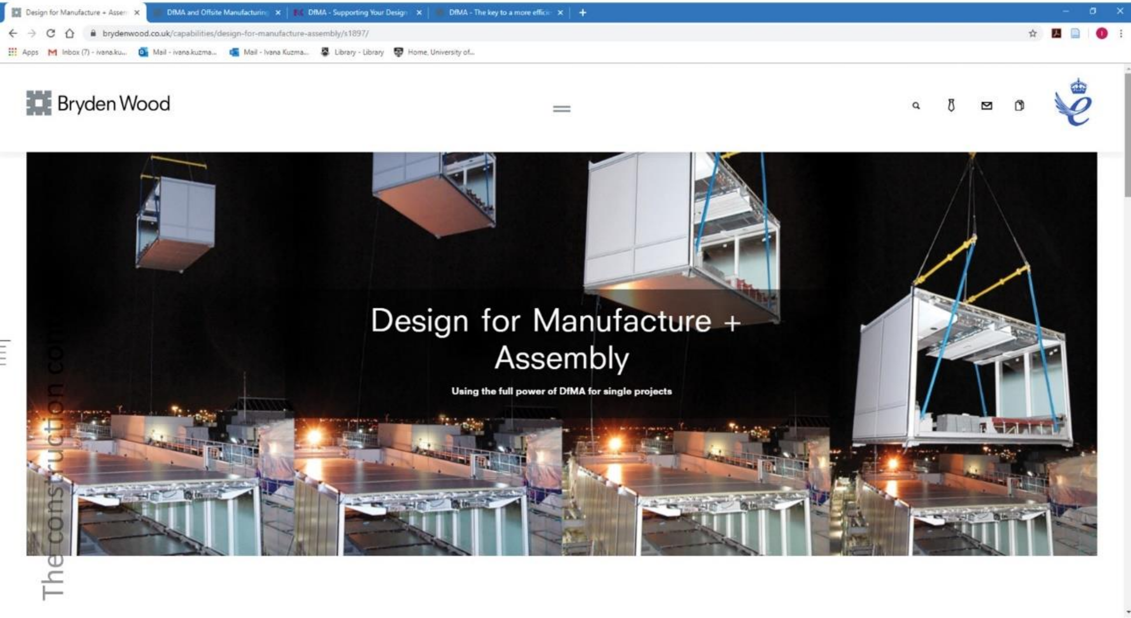
and yet...



fragmentation of specialist knowledge

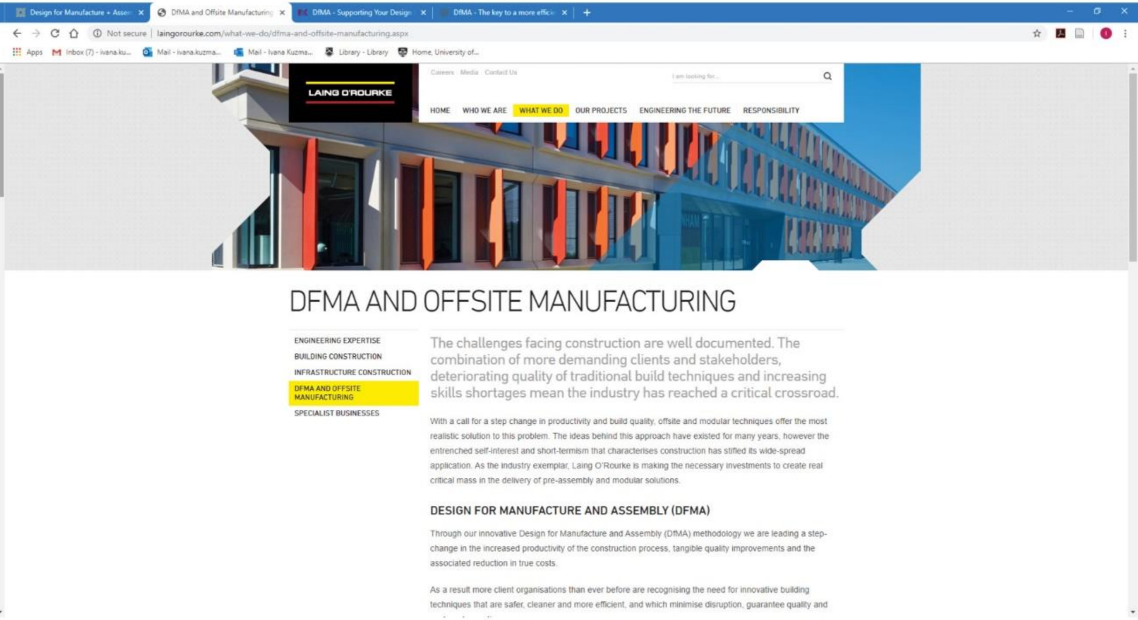
SOURCE | Eduardo Lyon, “Emergence and convergence of knowledge in building production: Knowledge-based design and digital manufacturing” in *Distributed Intelligence in Design*, ed. Tuba Kocatürk and Benachir Medjdoub (Blackwell Publishing Ltd., 2011), 93, Figure 6.14.

The construction com...


Bryden Wood

Design for Manufacture + Assembly

Using the full power of DfMA for single projects


LAING O'ROURKE

HOME | WHO WE ARE | WHAT WE DO | OUR PROJECTS | ENGINEERING THE FUTURE | RESPONSIBILITY

DFMA AND OFFSITE MANUFACTURING

ENGINEERING EXPERTISE
BUILDING CONSTRUCTION
INFRASTRUCTURE CONSTRUCTION
DFMA AND OFFSITE MANUFACTURING
SPECIALIST BUSINESSES

The challenges facing construction are well documented. The combination of more demanding clients and stakeholders, deteriorating quality of traditional build techniques and increasing skills shortages mean the industry has reached a critical crossroad.

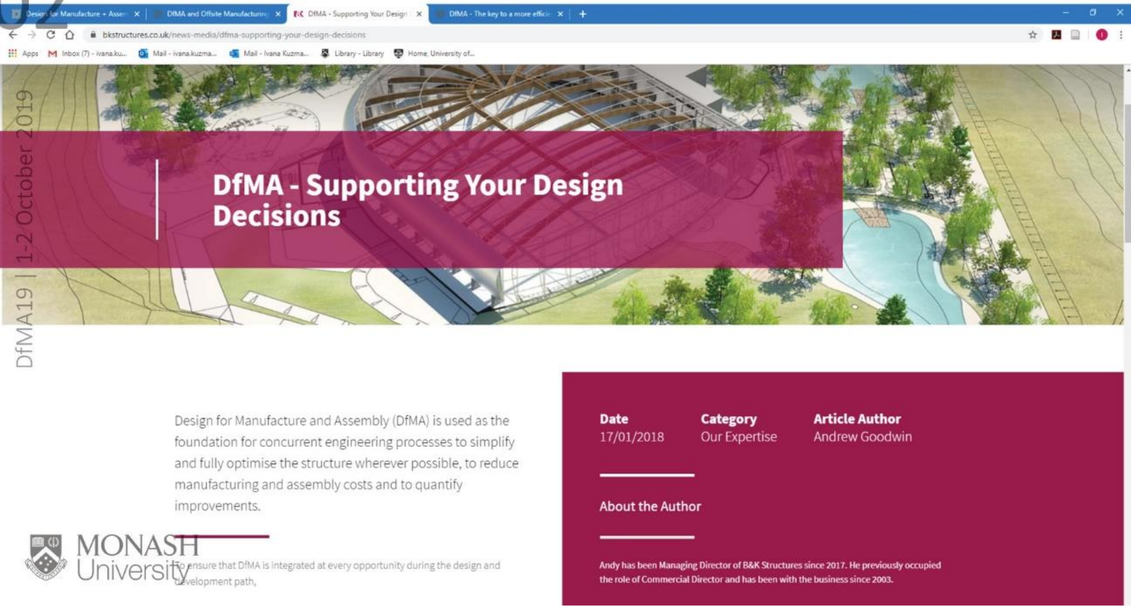
With a call for a step change in productivity and build quality, offsite and modular techniques offer the most realistic solution to this problem. The ideas behind this approach have existed for many years, however the entrenched self-interest and short-termism that characterises construction has stifled its wide-spread application. As the industry exemplar, Laing O'Rourke is making the necessary investments to create real critical mass in the delivery of pre-assembly and modular solutions.

DESIGN FOR MANUFACTURE AND ASSEMBLY (DFMA)

Through our innovative Design for Manufacture and Assembly (DfMA) methodology we are leading a step-change in the increased productivity of the construction process, tangible quality improvements and the associated reduction in true costs.

As a result more client organisations than ever before are recognising the need for innovative building techniques that are safer, cleaner and more efficient, and which minimise disruption, guarantee quality and

02


DfMA - Supporting Your Design Decisions

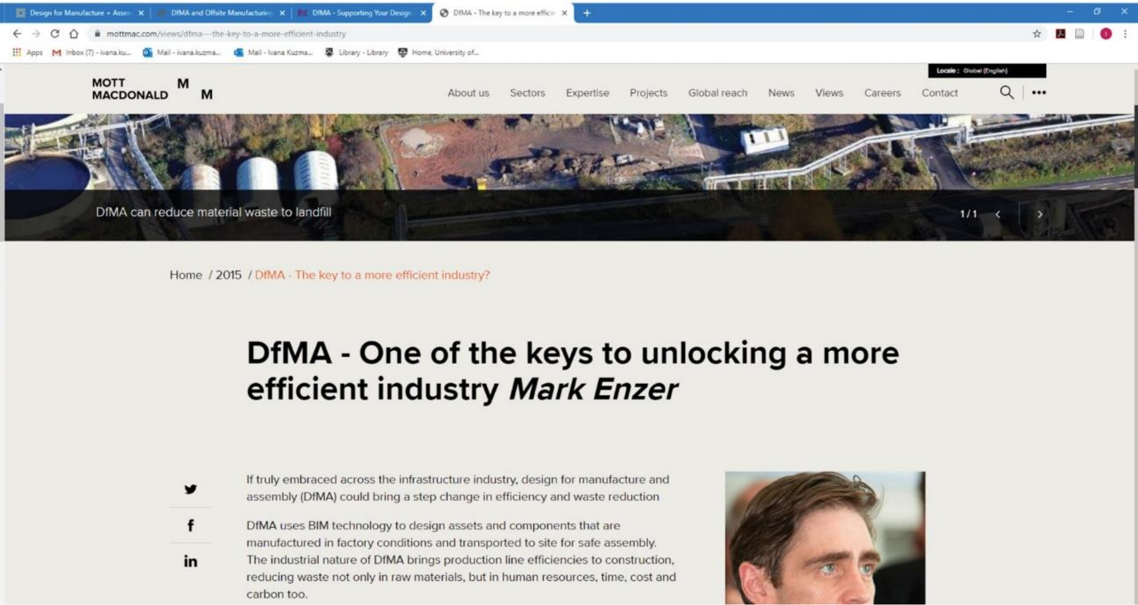
Design for Manufacture and Assembly (DfMA) is used as the foundation for concurrent engineering processes to simplify and fully optimise the structure wherever possible, to reduce manufacturing and assembly costs and to quantify improvements.

To ensure that DfMA is integrated at every opportunity during the design and development path,

Date	Category	Article Author
17/01/2018	Our Expertise	Andrew Goodwin

About the Author

Andy has been Managing Director of B&K Structures since 2017. He previously occupied the role of Commercial Director and has been with the business since 2003.


MOTT MACDONALD

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DfMA can reduce material waste to landfill

Home / 2015 / DfMA - The key to a more efficient industry?

DfMA - One of the keys to unlocking a more efficient industry *Mark Enzer*

If truly embraced across the infrastructure industry, design for manufacture and assembly (DfMA) could bring a step change in efficiency and waste reduction

DfMA uses BIM technology to design assets and components that are manufactured in factory conditions and transported to site for safe assembly. The industrial nature of DfMA brings production line efficiencies to construction, reducing waste not only in raw materials, but in human resources, time, cost and carbon too.

DfMA in the manufacturing context:

A "***systematic procedure***"[1] or "***discipline*** whereby products are designed so as to be as easy and cost effective to produce as possible."[2]

1 K.L Edwards, "Towards more strategic product design for manufacture and assembly: priorities for concurrent engineering", *Materials and Design* 23 (2002), 651.
2 Robert Bogue, "Design for manufacture and assembly: background, capabilities and applications", *Assembly Automation* 32, No.1 (2012): 112.

MANUAL HANDLING-ESTIMATED TIMES (s)

Key:
- One hand
- One hand with grasping aids
- Two hands for manipulation
- Two hands or assistance required for large size

Parts can be grasped and manipulated by one hand without the aid of grasping tools:

		Parts are easy to grasp and manipulate					Parts present handling difficulties (1)				
		Thickness >2 mm			Thickness ≤2 mm		Thickness >2 mm			Thickness ≤2 mm	
		Size >15 mm	6 mm ≤ size >15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm ≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
(α+β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

Parts can be grasped and manipulated by one hand but only with the use of grasping tools:

		Parts need tweezers for grasping and manipulation								Parts need standard tools other than tweezers	Parts need special tools for grasping and manipulation
		Parts can be manipulated without optical magnification				Parts require optical magnification for manipulation					
		Parts are easy to grasp and manipulate		Parts present handling difficulties (1)		Parts are easy to grasp and manipulate		Parts present handling difficulties (1)			
		Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm		
		0	1	2	3	4	5	6	7	8	9
α ≤ 180°, 0 ≤ β ≤ 180°	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
α ≤ 180°, β = 360°	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
α = 360°, α ≤ β ≤ 180°	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
α = 360°, β = 360°	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

		Parts present no additional handling difficulties					Parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		α ≤ 180°			α = 360°		α ≤ 180°			α = 360°	
		Size >15 mm	6 mm≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
Parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

		Parts can be handled by one person without mechanical assistance									Two persons or mechanical assistance required for parts manipulation
		Parts do not severely nest or tangle and are not flexible								Parts severely nest or tangle or are flexible (2)	
		Part weight < 10 lb				Parts are heavy (>10 lb)					
		Parts are easy to grasp and manipulate		Parts present other handling difficulties (1)		Parts are easy to grasp and manipulate		Parts present other handling difficulties (1)			
		α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°		
		0	1	2	3	4	5	6	7	8	9
Two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

MANUAL INSERTION-ESTIMATED TIMES (s)

Key:
- Part added but not secured
- Part secured immediately
- Separate operation

Addition of any part (1) where neither the part itself nor any other part is finally secured immediately:

		After assembly no holding down required to maintain orientation and location (3)				Holding down required during subsequent processes to maintain orientation at location (3)			
		Easy to align and position during assembly (4)		Not easy to align or position during assembly		Easy to align and position during assembly (4)		Not easy to align or position during assembly	
		No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)
		0	1	2	3	6	7	8	9
Part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Addition of any part (1) where the part itself and/or other parts are being finally secured immediately:

		No screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		Plastic deformation immediately after insertion						Screw tightening immediately after insertion	
				Plastic bending or torsion			Riveting or similar operation				
					Not easy to align or position during assembly			Not easy to align or position during assembly			
		Easy to align and position with no resistance to insertion (4)	Not easy to align or position during assembly and/or resistance to insertion (5)	Easy to align and position during assembly (4)	No resistance to insertion	Resistance to insertion (5)	Easy to align and position during assembly (4)	No resistance to insertion	Resistance to insertion (5)	Easy to align and position with no torsional resistance (4)	Not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
Part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

		Mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-fastening processes	
		None or localized plastic deformation				Metallurgical processes					
							Additional material required				
		Bending or similar process	Riveting or similar processes	Screw tightening or other processes	Bulk plastic deformation (large proportion of part is plastically deformed during fastening)	No additional material required (e.g. resistance, friction welding, etc.)	Soldering processes	Weld/braze processes	Chemical processes (e.g. adhesive bonding, etc.)	Manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	Other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	8
Assembly processes where all solid parts are in place	9	4	7	5	12	7	8	12	12	9	12

SOURCE | Geoffrey Boothroyd, Peter Dewhurst and Winston A. Knight, *Product Design for Manufacture and Assembly,* Third Edition, (Boca Raton: Taylor and Francis Group, 2011). 6-7

DfMA in the building design and production disciplines:

"DfMA is ***an approach*** which allows designers to maximise value for clients, maintain control over the delivery of their designs and facilitate the adoption of emerging methods, materials and technologies in construction best practice."[1]

"The DfMA approach redefines the traditional phases of project delivery. This means agreeing and locking down the design phase much earlier to allow the manufacturing, assembly, testing and commissioning phases to be compressed and run in parallel, rather than in one long linear sequence."[2]

"DfMA [...] is ***a system*** that takes the process of off-site manufacture one step further by identifying the most cost-effective material early in a structure's design, to speed construction and reduce costs."[3]

[1] *Delivery Platforms for Government Assets Creating a marketplace for manufactured spaces.* (Bryden Wood Technology Limited: 2017), 24.
[2] Colin Banks et al., "Enhancing High-Rise Residential Construction through Design for Manufacture and Assembly–a UK Case Study," Proceedings of the Institution of Civil Engineers-Management, Procurement and Law 171, no. 4 (2018). 165.
[3] Precast Concrete: optimising DfMA and lean construction in civil construction, 2017 http://www.roadsonline.com.au/precast-concrete-optimising-dfma-and-lean-construction-in-civil-construction/

Table 3 Design for Manufacturing and Assembly Technologies (DfMA) – N Value

DESIGN FOR MANUFACTURING AND ASSESMBLY TECHNOLOGIES (DFMA)		UNIT OF COVERAGE	N VALUE PERCENTAGE OF COVERAGE[1] ≥ 65% TO < 80%	≥ 80%
A1. First Class				
Fully Integrated System				
A1.1	Prefabricated Prefinished Volumetric Construction (PPVC)[2] *{The PPVC system has to be accepted by the Building Innovation Panel (BIP) and accredited under the PPVC Manufacturer Accreditation Scheme}*	area	8.00	10.00
A1.2	Prefabricated Prefinished Volumetric Construction (PPVC) meeting requirements stipulated under Sections 5.1 and 5.2	area	6.00	7.00
A2. 2nd Class (Upper)				
Fully Integrated Sub-assemblies				
A2.1	Mass Engineered Timber (e.g. Cross Laminated Timber, CLT)	area[3]	6.00	7.00
A2.2	Prefabricated Volumetric Construction (PVC)	area	5.00	6.00
A2.3	Structural steel with innovative connections[4]	area	5.00	6.00
A2.4	Steel-Mechanical, Electrical and Plumbing (MEP) floor system	area	5.00	6.00
A2.5	Prefinished wall with MEP services	length	1.00	2.00
A2.6	Prefinished ceiling with MEP services	area	1.00	2.00
A2.7	Prefabricated MEP modules integrated with work platform/catwalk	no.	3.00	5.00
	Prefabricated bathroom units (PBUs) pre-assembled off-site complete with finishes, sanitary wares, concealed	REPETITION OF LAYOUTS		

Table 3 Design for Manufacturing and Assembly Te – N Value (continued)

DESIGN FOR MANUFACTURING AND ASSESMBLY TECHNOLOGIES (DFMA)	
A4. 3rd Class	
Prefabricated Components	
A4.1	Integrated precast components comprising at least 2 elements (e.g. multi-tier column/wall, double bay façade wall)
A4.2	Precast external wall with cast-in windows
A4.3	Mechanical connection for precast column/precast wall (horizontal joints)
A4.4	Mechanical connection for precast beam joints
A4.5	Mechanical connection for precast wall (vertical joints)
A4.6	Prefabricated wall/facade with onsite dry applied finishes
A4.7	Prefabricated slab with onsite dry applied finishes
A4.8	Prefabricated ceiling with onsite dry applied finishes
A4.9	Prefabricated and pre-insulated duct for air-conditioning system[5] ***(Mandatory for all projects)***
A4.10	Flexible sprinkler dropper[5]
A4.11	Flexible water pipes[5]
A4.12	Common M&E bracket (at least 3 M&E services)[5]

DfMA “technologies”

SOURCE | Building and Construction Authority, *Code of Practice on Buildability,* (Singapore: Building and Construction Authority, 2017), 47-48.

1 DEFINE PRODUCT CONCEPT

SIMPLIFICATION

2 APPLY DFA.

REDUCE PART COUNT AND PART TYPES

a. Is the part needed? Apply the three fundamental criteria.
b. Eliminate separate fasteners by using integral locking features.
c. Eliminate parts that act as conduits on connections.
d. Design multi-functional parts by exploiting manufacturing processes.
e. Do not focus on piece part producibility at the early stage of design.
f. Eliminate any product features which do not add value to the customer.

DESIGN PARTS FOR EASY HANDLING

g. Maximise part symmetry or design parts to be obviously assymmetrical.
h. Provide features to prevent jamming or nesting when stored in bulk.
i. Avoid features that can tangle.
j. Avoid parts that are slippery, delicate, flexible, very small or very large.

EASY INSERTION AND FASTENING

k. Standardise parts, processes and methods across all models and lines.
l. Design for progressive assembly about one axis. Assemble from above!
m. Design parts to be self locating and self aligning.
n. Use chamfers and tolerances to avoid jamming.
o. Avoid the need to hold parts down.
p. Minimise reorientations during assembly.
q. Minimise adjustments.
r. Use kinematic design principles.
s. Do not restrict access for assembly operations

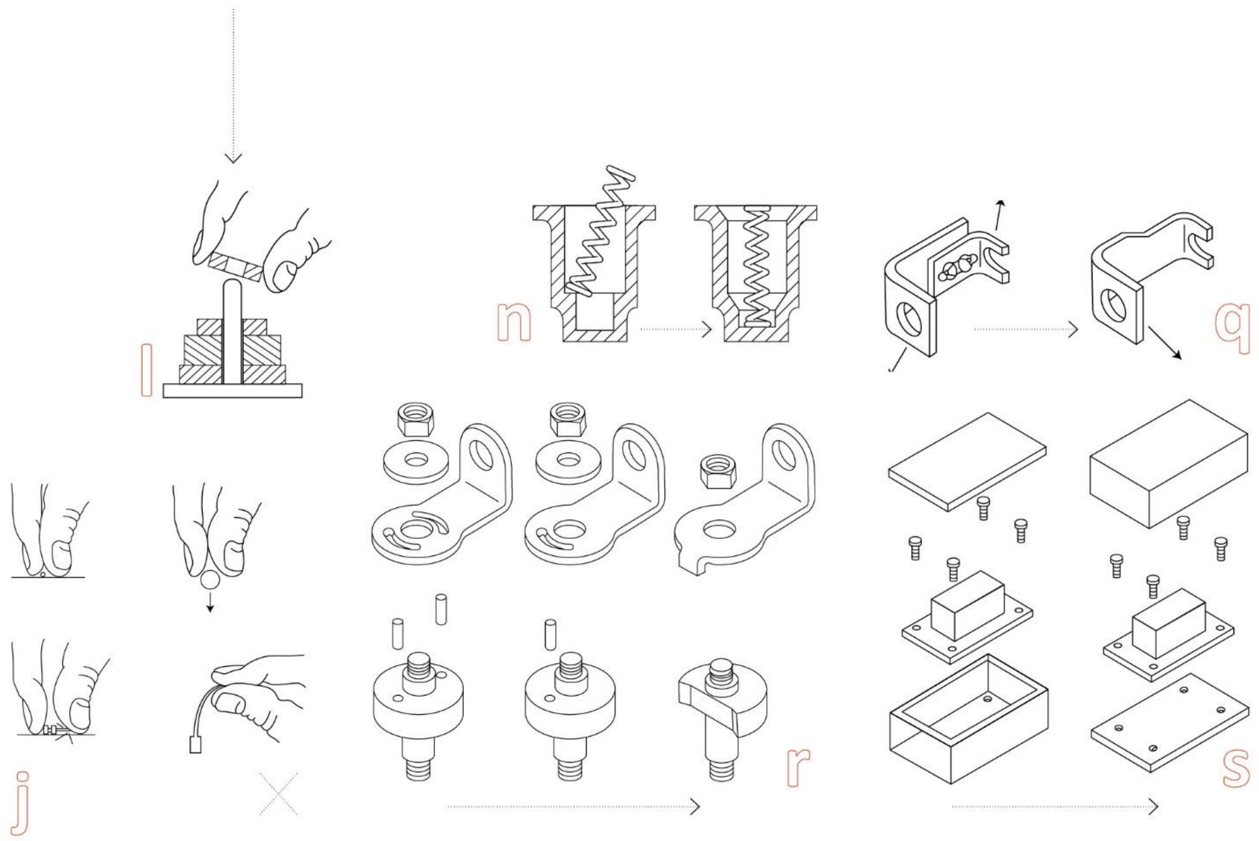
MORE ECONOMIC MATERIALS AND PROCESSES

3 SELECT MATERIALS + EARLY DFM COST ESTIMATES.

4 APPLY DFM

EACH FABRICATION PROCESS HAS ITS OWN GUIDELINES

Materials and processes chosen based on product life volume, permissible tooling expenditure, possible part shape and complexity, service or environment factors, accuracy factors, appearance.



Boothroyd + Dewhurst guidelines

SOURCE | Geoffrey Boothroyd, Peter Dewhurst and Winston A. Knight, *Product Design for Manufacture and Assembly,* Third Edition, (Boca Raton: Taylor and Francis Group, 2011). 6-7

Buildability's lack of success partly due to:

/ a lack of shared understanding of best practice in construction

/ lack of manuals on material, component or process data for qualified comparisons between the alternatives

/ lack of metrics for comparative evaluation and lack of collaboration between manufacturing, assembly and plant companies.

SOURCE | Stephen Fox, Laurence Marsh, and Graham Cockerham, "Constructability Rules: Guidelines for Successful Application to Bespoke Buildings," *Construction Management and Economics* 20, no. 8 (2002).

26 Scopus articles refer specifically to DfMA in construction,
9 were published since 2018.

SOURCE | Shang Gao, Ruoyu Jin and Weisheng Lu, "Design for manufacture and assembly in construction: a review", *Building Research & Information* (2019), 4.

Three primary objectives of research in the literature:

Three primary objectives of research in the literature:

01 Identifying and obtaining relevant production information to inform design decisions.
(often looking to existing work on buildability)

/ Method for identifying, collating + organising relevant constructability information
(Fox, Marsh + Cockerham, 2002)

/ Design for Construcion by examining waste in precedent projects
(Gerth et al., 2013)

/ Liang O'Rourke's confidenial DfMA operative model
(Banks et al. 2018)

Three primary objectives of research in the literature:

01 Identifying and obtaining relevant production information to inform design decisions.
(often looking to existing work on buildability)

02 Developing methodologies for applying production knowledge in the design process.

/ Discipline specific framework for digital design
(Lyon, 2011)

/ DfMCMA using BIM and block-chain platforms
(Kremer, 2018)

/ Framework for capturing constructability knowledge so that it is useful for design
(Fischer + Tatum 1994)

Three primary objectives of research in the literature:

01 Identifying and obtaining relevant production information to inform design decisions.
(often looking to existing work on buildability)

02 Developing methodologies for applying production knowledge in the design process.

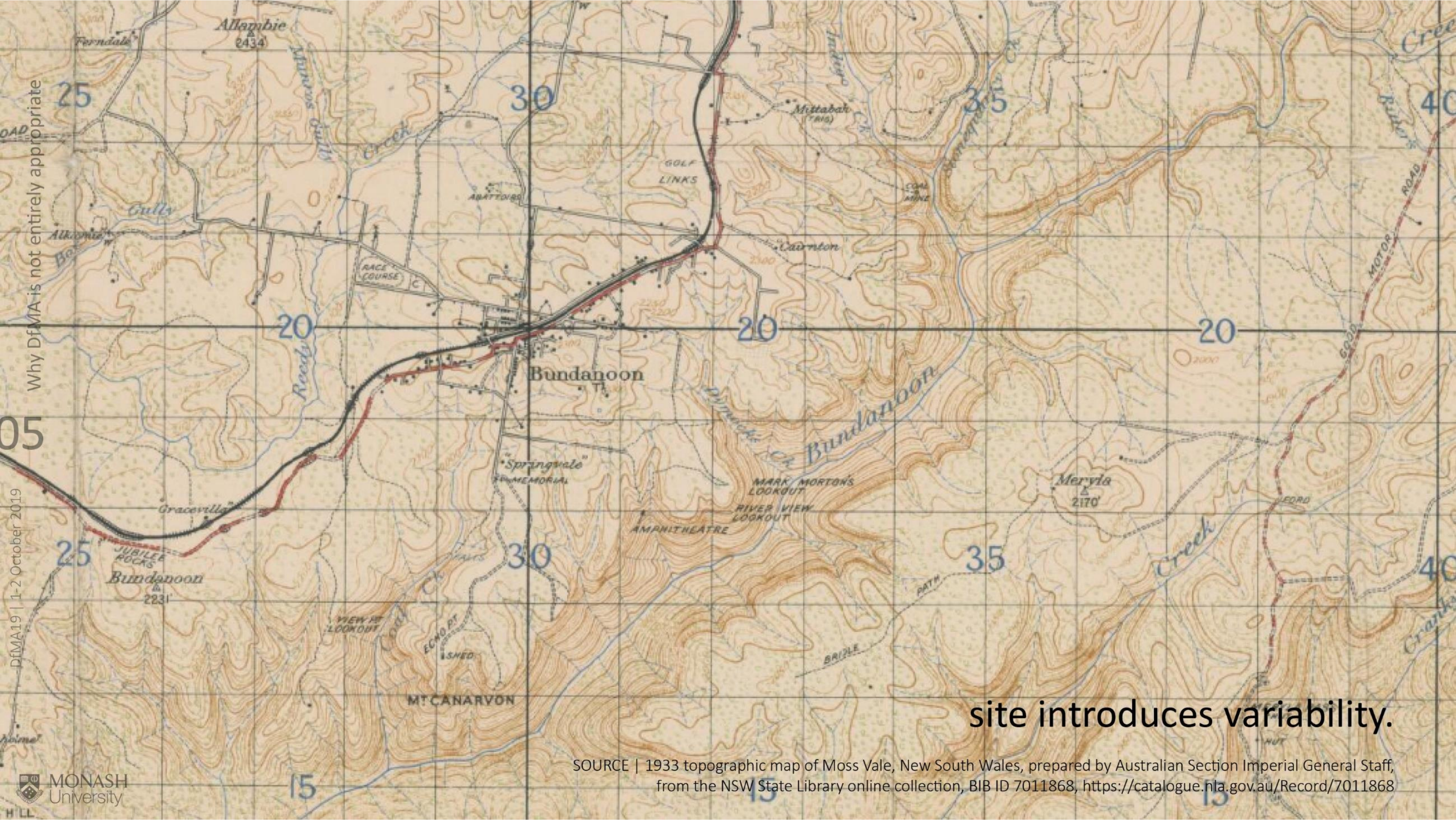
03 Investigating optimisation techniques.

/ Optimisation method based on relevant parameters
(Giuda et al., 2019)

/ Axiomatic Design

why?

production context

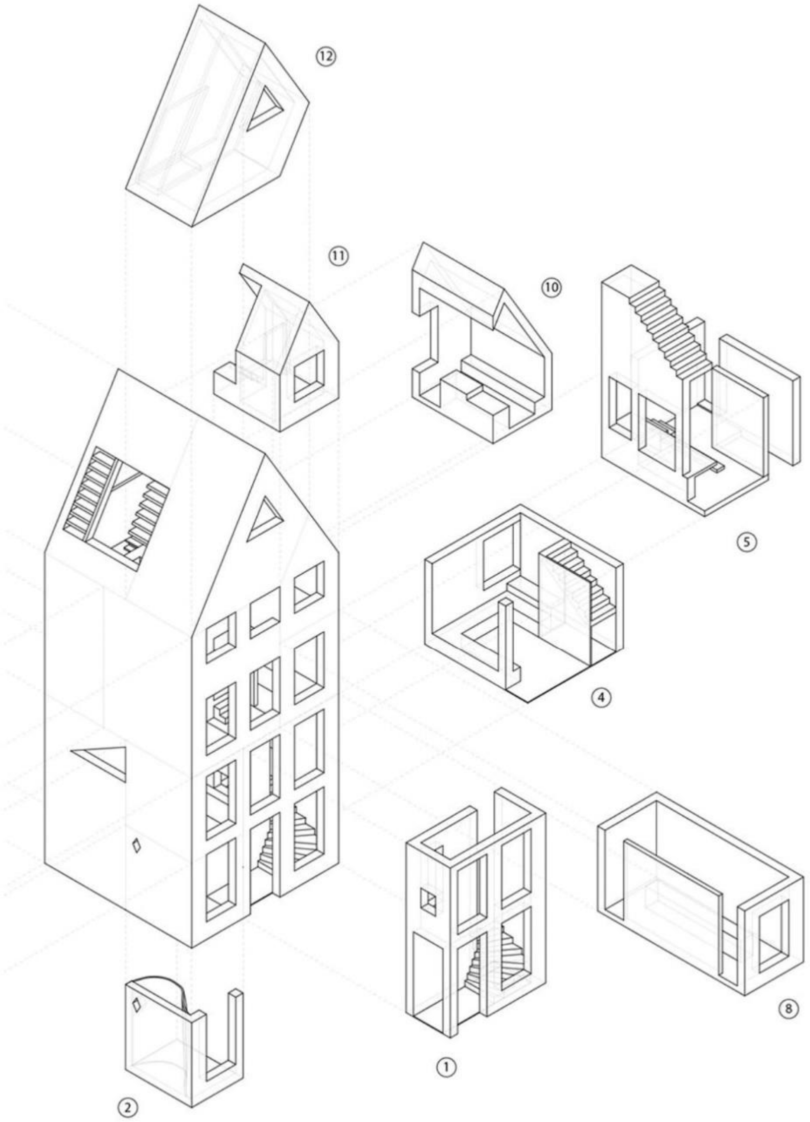


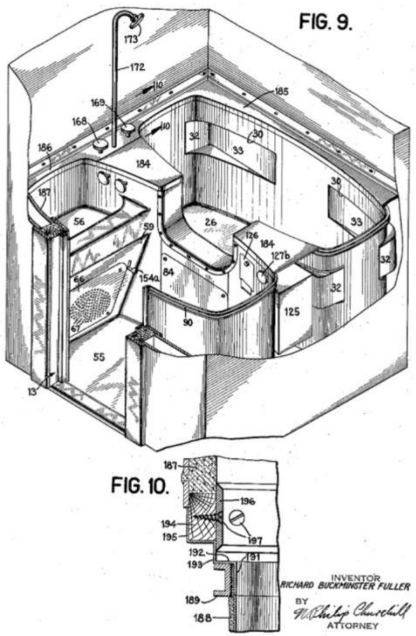
site introduces variability.

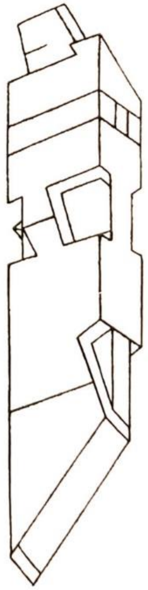
SOURCE | 1933 topographic map of Moss Vale, New South Wales, prepared by Australian Section Imperial General Staff, from the NSW State Library online collection, BIB ID 7011868, https://catalogue.nla.gov.au/Record/7011868

factory

site

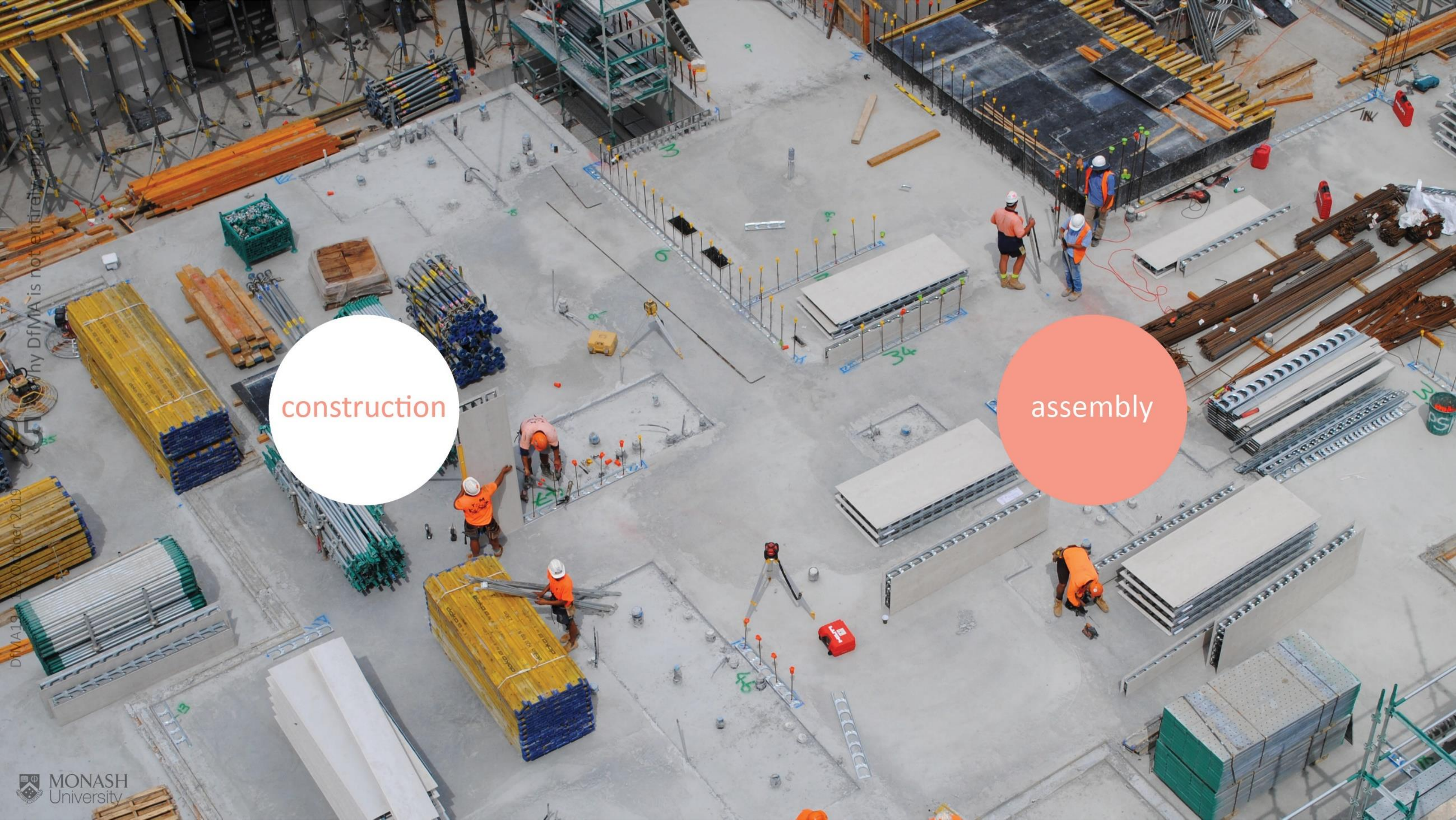






modules limited by transportability

LEFT | 3D Print Canal House and Urban Cabin by DUS Architects, images from http://3dprintcanalhouse.com
MID | Buckminster Fuller's 1938 patent for a modular bathroom made of 4 pieces of pressed metal sheet.
RIGHT | Illustration from the Ying Tsao Fa Shi, reproduced in Utzon by Richard Weston


construction
assembly

05

production context

/ Factory x Site
/ Variability
/ Construction x Assembly

production context

scale

05

/ Factory x Site
/ Variability
/ Construction x Assembly

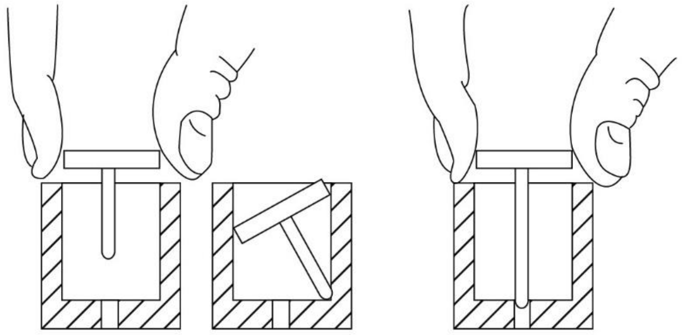


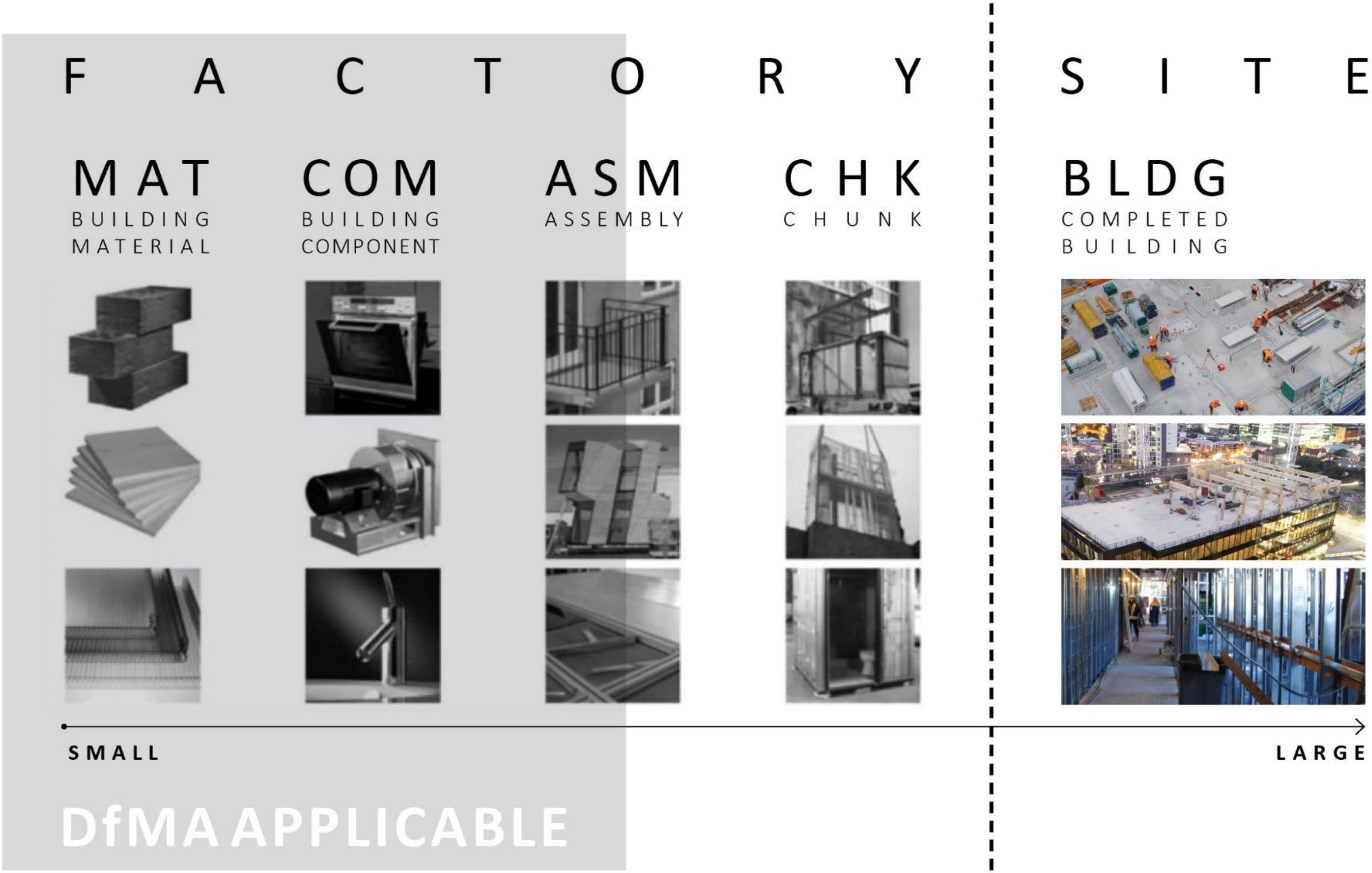
FIGURE 3.10
Design to aid insertion.

buildings are large.

SOURCE | Geoffrey Boothroyd, Peter Dewhurst and Winston A. Knight, *Product Design for Manufacture and Assembly,* Third Edition, (Boca Raton: Taylor and Francis Group, 2011). 78

"Obviously, one database of assembly times cannot be accurate for all situations."

SOURCE | G. Boothroyd and M. C. Fairfield, "Assembly of Large Products", Annals of the CIRP 40, no. 1 (1991), 1.



the nature of building production.

SOURCE | Diagram adapted from Kasper Sanchez Vibaek, "System Structures: A Theory of Industrialised Architecture", in Ryan E. Smith and John D. Quale, *Off-site Architecture, Constructing the Future* (Routeledge, 2017), 30.


Why DfMA is not entirely appropriate
05
DfMA19 | 1-2 October 2019
MONASH University
crane lifting and assembly
ORIEL
ACCESS HIRE

05

approaches to tolerance management

production context

/ Factory x Site
/ Variability
/ Construction x Assembly

scale

/ Assembly strategy
/ Lifting logistics
/ Instal logistics
/ Tolerance

production context

scale

design objectives

/ Factory x Site
/ Variability
/ Construction x Assembly

/ Assembly strategy
/ Lifting logistics
/ Instal logistics
/ Tolerance

ergonomics + safety

delight!

SOURCE | Door handle design by PKdM, image by Rafael Pinho,
found at https://divisare.com/projects/347093-pkdm-rafael-pinho-pkdm-office

05

production context

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design objectives

/ Beyond cost + time?
/ Safety
/ Quality

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/ Tolerance

design objectives

/ Beyond cost + time?
/ Safety
/ Quality

design methods

DfMA refers to the *“detailing of the materials, shapes and tolerance of the individual parts of a product”* rather than the aesthetic decisions that are made in the conceptual design phase; *“the external shape of a car, or the colour, texture and shape of the casing of a can opener.”*

SOURCE | Geoffrey Boothroyd, Peter Dewhurst and Winston A. Knight, *Product Design for Manufacture and Assembly,* Third Edition, (Boca Raton: Taylor and Francis Group, 2011). 6-7

05

RIBA

RIBA Plan of Work **Designing for Manufacture and Assembly overlay**

www.offsiteschool.com/DfMA

This Overlay to the RIBA Plan of Work 2013 includes additional task bars to support Designing for Manufacture and Assembly. It should be used in conjunction with the RIBA Plan of Work 2013: www.ribaplanofwork.com

RIBA Plan of Work 2013 — Stages / Tasks	0 Strategic Definition	1 Preparation and Brief	2 Concept Design	3 Developed Design	4 Technical Design	5 Construction	6 Handover and Close Out	7 In Use
Core Objectives from the RIBA Plan of Work	Identify client's **Business Case** and **Strategic Brief** and other core project requirements.	Develop **Project Objectives**, including **Quality Objectives** and **Project Outcomes**, **Sustainability Aspirations**, **Project Budget**, other parameters or constraints and develop **Initial Project Brief**. Undertake **Feasibility Studies** and review of **Site Information**.	Prepare **Concept Design**, including outline proposals for structural design, building services systems, outline specifications and preliminary **Cost Information** along with relevant **Project Strategies** in accordance with the **Design Programme**. Agree alterations to brief and issue **Final Project Brief**.	Prepare **Developed Design**, including coordinated and updated proposals for structural design, building services systems, outline specifications, **Cost Information** and **Project Strategies** in accordance with the **Design Programme**.	Prepare **Technical Design** in accordance with the **Design Responsibility Matrix** and **Project Strategies** to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with the **Design Programme**.	Offsite manufacturing and onsite **Construction** in accordance with the **Construction Programme** and resolution of **Design Queries** from site as they arise.	Handover of building and conclusion of the **Building Contract**.	Undertake **In Use** services in accordance with **Schedule of Services**.
DfMA Strategy	Consider opportunities for applying DfMA across portfolios or programmes of projects. Consider how DfMA might impact on the **Business Case** or **Strategic Brief**. Consider whole life issues in the **Strategic Brief** including options for reuse or repurposing and recycling of components at the end of the building's life. Consider **Research and Development** that might assist **Feasibility Studies** or the **Concept Design** including intellectual property issues.	Initiate DfMA thinking and incorporate client requirements into the **Initial Project Brief**. This should include high-level targets for the extent of DfMA adoption and time/cost/waste savings against traditional benchmarks. Consider opportunities for 'repeatability', site/logistical constraints, **Research and Development** and early input required from specialist subcontractors. Consider best practice DfMA exemplars for comparable projects. Test the feasibility of high-level DfMA objectives included in the **Initial Project Brief** using the **Site Information** and **Feasibility Studies**.	Test initial **Concept Design** options against the DfMA aspirations set out in the **Initial Project Brief**. Identify opportunities for the greatest impact and initiate any **Research and Development** required to integrate DfMA into the **Concept Design**. Prepare the **Construction Strategy** considering high-level DfMA benefits including safety, productivity, quality and sustainability, considering topics such as eliminating scaffolding, wet or hot works, the delivery methodology and the suitability of proposed systems. Consider DfMA aspects in **Risk Assessments** and the **Health and Safety** and **Maintenance and Operational Strategies**. Ensure that the **Cost Information** takes account of the DfMA methodologies set out in the **Construction Strategy**.	Update the **Construction Strategy** taking into account DfMA opportunities appropriate to the **Developed Design** and coordination activities. Prepare a schedule of DfMA components and consider national (or other) standards appropriate for DfMA. Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces. Update **Cost Information** taking into account discussions with potential contractors, specialist subcontractors and suppliers. Update **Risk Assessments** and the **Health and Safety** and **Maintenance and Operational Strategies** taking into account DfMA considerations.	Develop the DfMA components more accurately considering the implications of the possible methods of manufacturing or fabrication. Develop the interfaces and specifications including structural, water/moisture/vapour penetration and acoustic issues. Update the **Construction Strategy** considering the lifting, handling and transportation strategy for each component and sub-assembly. Consider manufacturing and assembly risks in the updated **Risk Assessment** and **Health and Safety Strategy**. Develop a commissioning plan optimising the use of factory acceptance testing.	Update the **Construction Strategy**, including a logistics plan that ensures the right materials, plant and operatives are deployed in the right place at the right time. Commission the building progressively and capture **'As-Constructed' Information**. Consider how DfMA impacts the **Construction Programme**.	Consider how to capture commissioning and **'As-Constructed' information** in a manner that will assist the **In Use** stage including the potential disassembly of the building.	Consider any **Feedback** during the **In Use** stage necessary to inform future projects. Monitor the performance of standardised components including maintenance and replacement and provide **Feedback**. Monitor disassembly or potential reuse of materials during demolition at the end of the stage and provide **Feedback**.
Suggested BIM Tasks for DfMA	Analyse data from the existing building to identify key metrics for success. Gather cost and programme data from previous projects to set benchmarks. Consider establishing a BIM object	Use BIM for the preparation of **Feasibility Studies** including data-rich 'placeholder' objects with limited geometry to assist in the preparation of **Cost Information**. Use BIM to test and optimise the **Initial Project Brief**. Include the Level of Development	Develop the BIM model and components to next Level of Development set out in the **Design Responsibility Matrix**. Validate the model against the client's information requirements. Consider DfMA tolerances in the development of the BIM model.	Progress the BIM model and components to next Level of Development as set out in the **Design Responsibility Matrix**. Validate the model against the client's information requirements. Use digital technologies as part of coordination exercises.	Progress the BIM model and components to next Level of Development as set out in the **Design Responsibility Matrix**. Validate the model against the client's information requirements. Use 4D technologies to test and rehearse the sequencing set out in	Use BIM to train site operatives. Use digital technologies to track each step of the manufacturing, packing, logistics and delivery process. Consider recording the complete history and location of every	Ensure any relevant documentation relating to DfMA components is linked to BIM components for **Feedback**, including lessons learned and potential repurposing.	Consider configuration management techniques to maintain an up-to-date record (BIM model) of the building.

SOURCE | Sinclair et al., *RIBA Plan of Work 2013 Design for Manufacture and Assembly,* (Newcastle upon Tyne: RIBA Publishing, 2013), 36.

RIBA

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www.offsiteschool.com/DfMA

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RIBA Plan of Work 2013 / Stages / Tasks	4 Technical Design	5 Construction	6 Handover and Close Out	7 In Use
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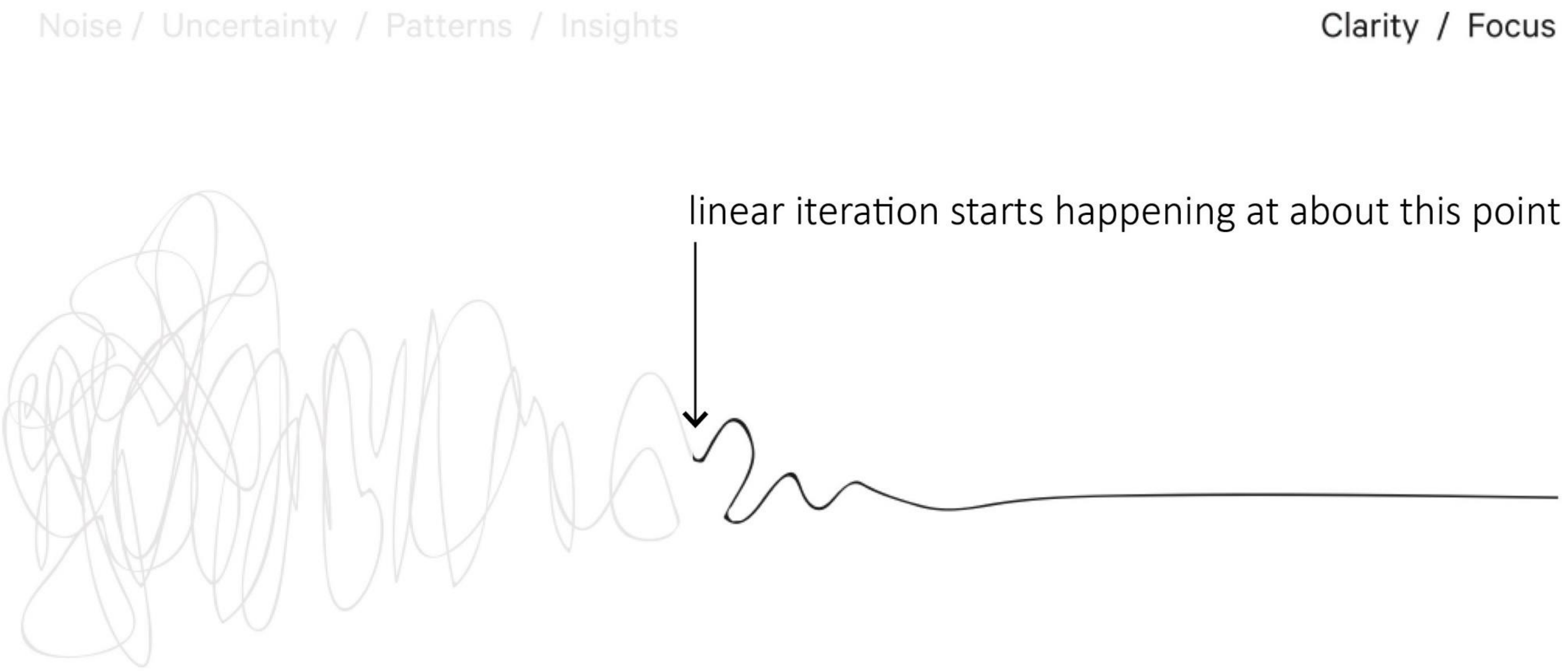
SOURCE | Sinclair et al., *RIBA Plan of Work 2013 Design for Manufacture and Assembly,* (Newcastle upon Tyne: RIBA Publishing, 2013), 36.

“designerly” vs. scientific approach

SOURCE | Daniel Newman’s “Design Squiggle” found at https://thedesignsquiggle.com/



“designerly” vs. scientific approach

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/ Instal logistics
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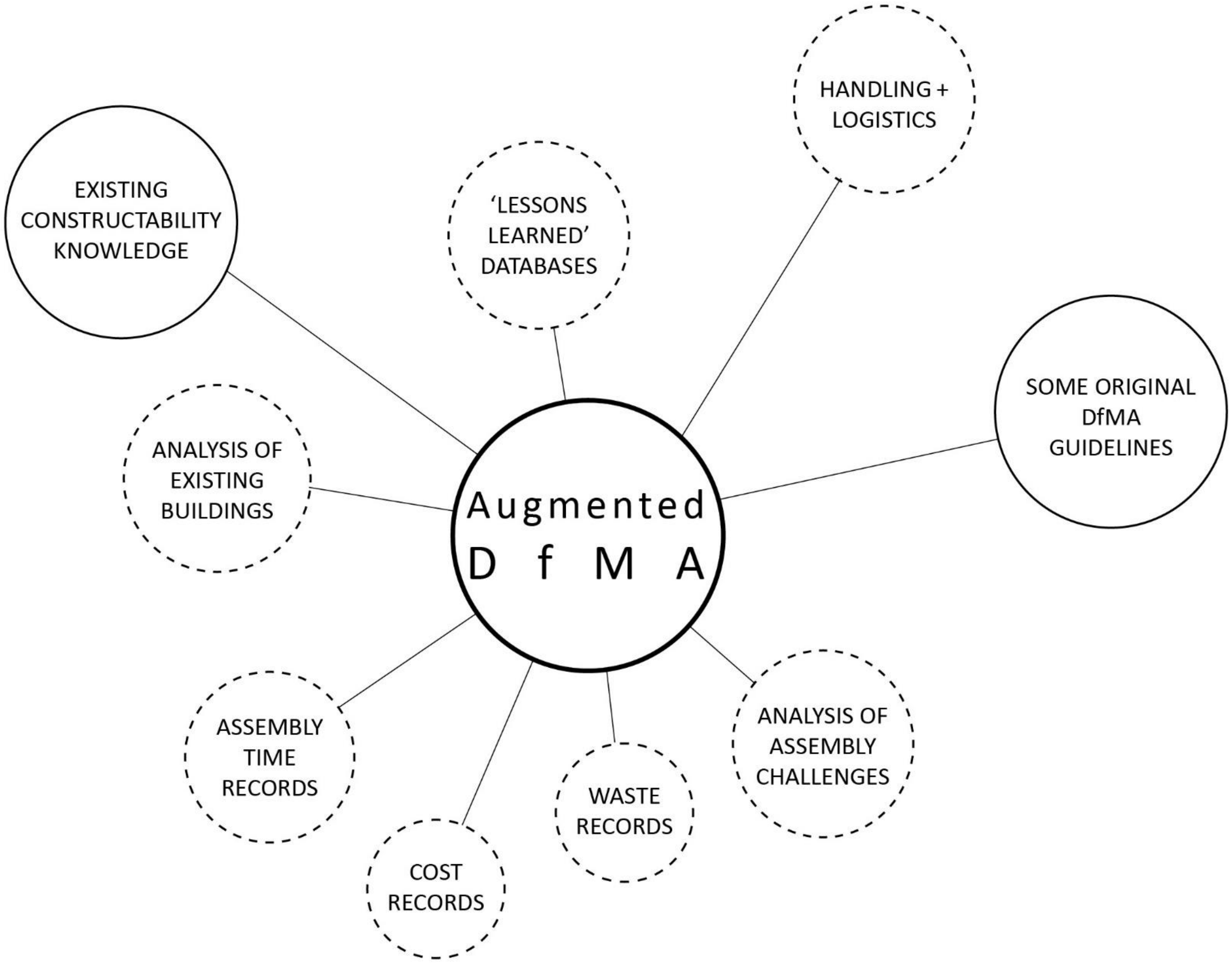
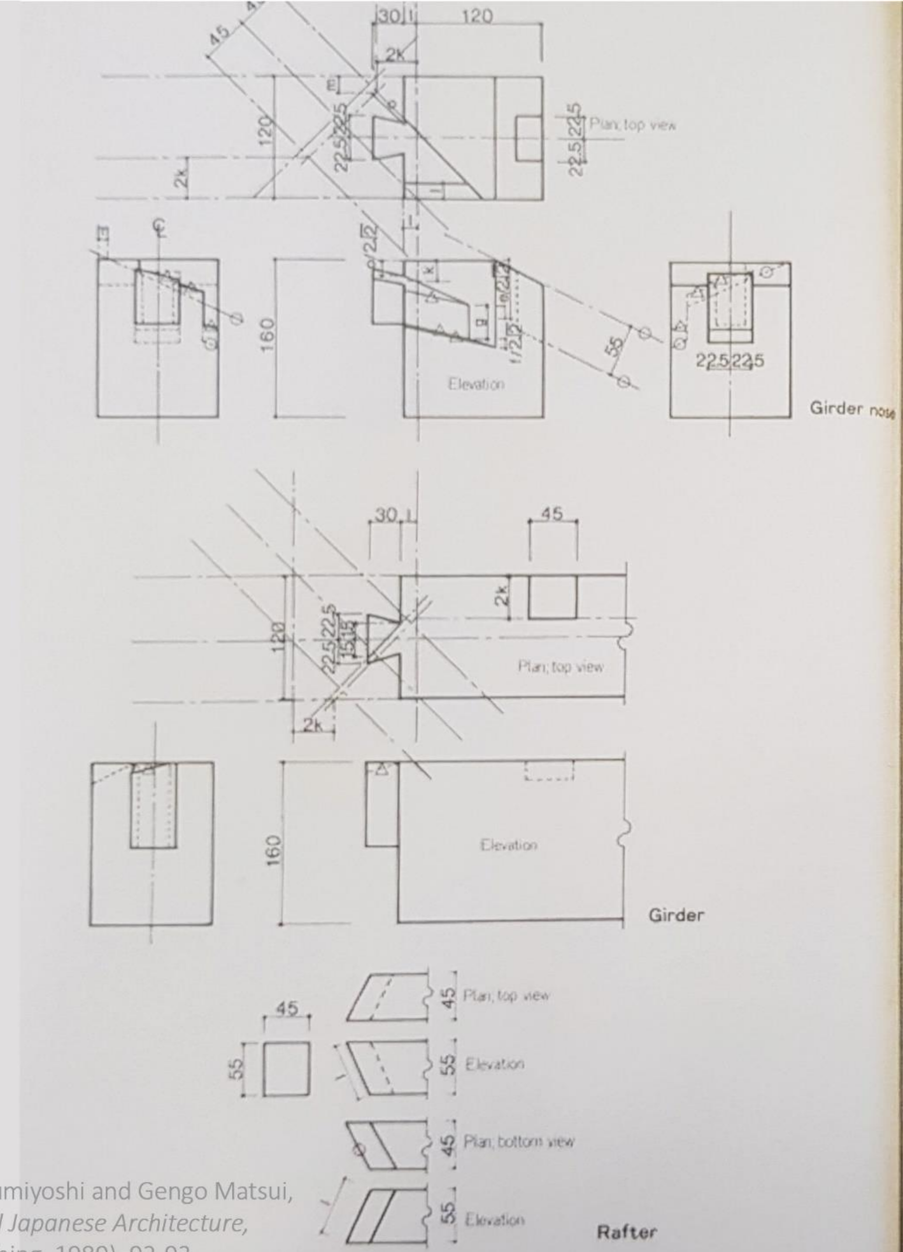
design objectives

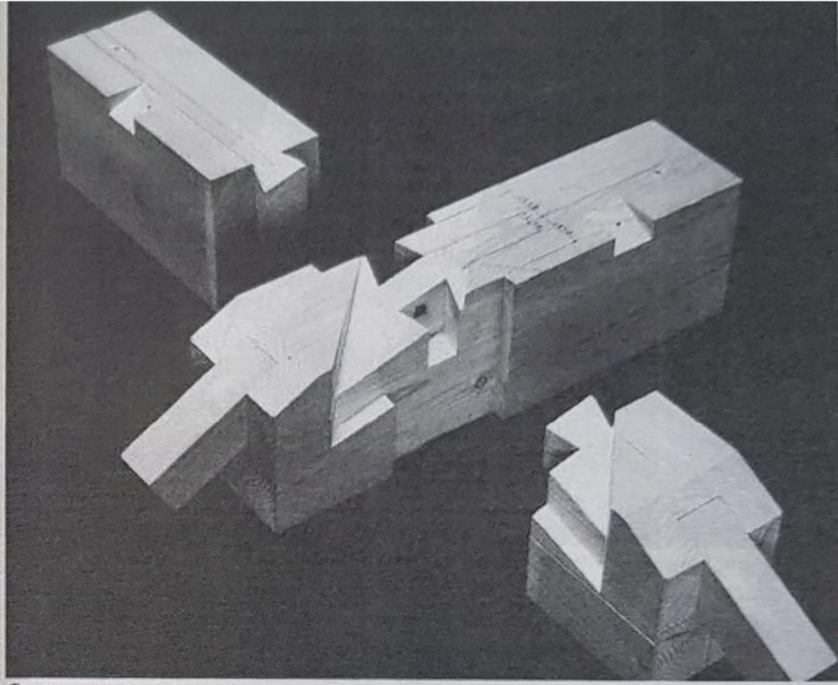
/ Beyond cost + time?
/ Safety
/ Quality

design methods

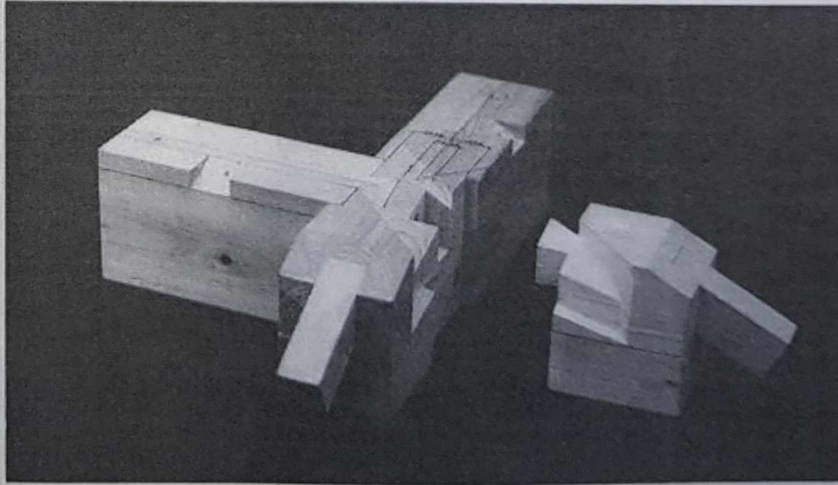
/ Stages of design
/ Scientific vs Designerly
/ Attitudes towards optimisation


EXISTING CONSTRUCTABILITY KNOWLEDGE
'LESSONS LEARNED' DATABASES
HANDLING + LOGISTICS
SOME ORIGINAL DfMA GUIDELINES
ANALYSIS OF EXISTING BUILDINGS
Augmented DfMA
ASSEMBLY TIME RECORDS
COST RECORDS
WASTE RECORDS
ANALYSIS OF ASSEMBLY CHALLENGES





❶ Arrangement of girders A and B and of the girder nose



❷ Girder B is inserted into girder A (housed dovetail).

SOURCE | Torashichi Sumiyoshi and Gengo Matsui, *Wood Joints in Classical Japanese Architecture*, (Kajima Institute Publishing, 1989), 92-93.

thank you.

ivana.kuzmanovska@monash.edu

https://www.monash.edu/mada/research/labs/future-building-initiative