SUPPLEMENTAL MATERIALS

ASCE *Journal of Legal Affairs and Dispute Resolution in Engineering Construction*

Liability Factors and Conceptual Framework for Contracts to Manage Design for Digital Fabrication in Construction Projects

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DOI: 10.1061/(ASCE)LA.1943-4170.0000578

TABLE S1. Qualifications of the 14 experts for the Delphi survey. Abbreviation: DFAB = digital fabrication

	Role for Project Q	Current position	Profession	Experience of work Contracts	Experience of work Abroad
1	Project owner	Project Manager	Project Manager	✓	
2	Project owner	Engineer	Civil Engineer		
3	Design Architect	Director	Architect	✓	✓
4	Design Architect	Director	Architect	✓	✓
5	Executive Architect	Vice President	Architect	✓	
6	Executive Architect	Vice President	Architect	✓	✓
7	General Contractor	Vice President	Civil Engineer & Contract Manager	✓	✓
8	General Contractor	Project Manager	Architect & Project Manager	✓	
9	DFAB Trade Contractor	Vice President	Civil Engineer	✓	
10	BIM Consultant	President	BIM Manager	✓	✓
11	BIM Consultant	Project Manager	BIM Manager		
12	Facade Consultant	Consultant	Facade Engineer		✓
13	Geometry Design Consultant	Architect Lead	Architect		✓
14	Geometry Design Consultant	Director	Architect	✓	✓

TABLE S2. 163 liability factors identified in this work. Abbreviation: DFAB = digital fabrication; n = total number of valid observations = 163; μ = mean; σ = standard deviation.

	Round 1, Round 2 and Round 3							Ranked by		
ACTORS (n=13)	μ	Med.	σ	Min.	Max.	n	R1 n	μ	σ	**Definition**
General Contractor	4.36	5	0.93	3	5	14	4	3	62	Team(s) who is responsible for the overall coordination in delivery of a project
DFAB Trade contractor	3.79	4	0.89	2	5	14	5	59	54	Team(s) who is responsible for delivering the digital fabrication
Executive architect	3.79	4	1.12	1	5	14	7	60	107	Team(s) who is responsible for delivering the design (incl. design intents) through the construction
On-site assembly contractor	3.75	4	1.14	2	5	12	1	71	111	Team(s) who is responsible for on-site assembling the system(s) which has been fabricated digitally
3D Modeller	3.71	4	1.2	1	5	14	1	78	124	Team(s) who is responsible for modelling in 3D
BIM specialist	3.71	4	1.14	1	5	14	4	79	112	Team(s) who is responsible for/specialising in BIM-based work (e.g. modelling using BIM-based platforms)
DFAB engineer	3.71	4	0.99	2	5	14	1	80	78	Team(s) who is responsible for the engineering design work for the digital fabrication
Project manager	3.64	4	1.08	1	5	14	2	89	100	Team(s) who is responsible for managing the project throughout the process from design to construction completion
Design architect	3.57	4	1.28	1	5	14	6	102	134	Team(s) who is responsible for delivering the design concept and the design intents
Project owner	3.5	3	1.16	2	5	14	5	109	115	Team (s) who provides the project brief and owns the project asset after construction completion
Design engineer	3.43	4	1.34	1	5	14	2	122	139	Team(s) who is responsible for delivering the engineering design (e.g. structural design, MEP design)
Consultant	3.14	3	1.25	1	5	15	4	149	129	Team(s) who assist certain part(s) of the project deliverables (e.g. facade systems, geometry design)
3D scanning specialist	3.14	3	1.48	0	5	14	1	159	157	Team(s) who is responsible for the 3D scanner execution or consulting work
	Rounds 1, 2 and 3							Rk. by		
RESOURCES (n=18)	μ	Med.	σ	Min.	Max.	n	R1 n	μ	σ	**Definition**
Management capability	4.45	5	0.69	3	5	11	2	1	11	Capability to manage the digital design and digital fabrication process
BIM expertise	4.43	5	0.85	3	5	14	5	2	46	Expertise in BIM-usage for design, construction and project management
BIM modelling coordination platform	4.36	5	0.84	3	5	14	5	4	44	BIM-based platform(s) that enables modelling and coordination work amongst multi-disciplinary teams
Platform's 3D interface capability	4.29	4.5	0.91	2	5	14	1	6	59	Capacity to handle the interface(s) between systems in 3D within the platform(s)
Platform for performance analysis	4.17	4.5	1.03	2	5	12	3	15	87	Platform(s) that enables performance analysis during the design/construction process (eg structural analysis)
Coordination/information exchange platform	4.08	4	0.79	3	5	12	3	22	31	Platform(s) that enables coordination or exchange of design/digital fabrication information amongst multi-disciplinary teams
Technical skillset	4.08	4	0.95	2	5	13	7	23	68	Skills to handle technical aspects (eg system design detailing or robotic control) in design and/or construction
Affordable BIM platform	4	4	1.22	1	5	13	1	34	126	BIM-based platform(s) which is affordable by most people in terms of price
High-performance hardware	3.93	4	1	2	5	14	3	40	81	Hardware (eg computer) that has a high-performance specification (eg with high-speed processor)
DFAB machine	3.77	4	1.36	2	5	13	2	64	141	Machine(s)/equipment/tool(s) to execute the digital fabrication
Fabrication method intents	3.58	3.5	1.44	1	5	12	2	98	156	Concept/idea that captures the proposed fabrication method to be executed in the construction process
Precise design provision	3.54	4	1.13	2	5	13	1	104	109	Providing accurate and detailed design information and documentation
Cost control system	3.38	3	0.87	2	5	13	1	126	49	System/mechanism/approach that assists in controlling costs in a project
Project lifecycle management platform	3.31	4	1.03	1	5	13	1	134	88	Platform(s) that enables lifecycle assessment and the corresponding management approaches
3D Point cloud technology	3.23	3	1.36	1	5	13	3	142	142	Technology that generates 3D point cloud model/visualisation/data
Flexible interface system	3.15	4	1.07	1	5	13	1	147	96	Interface system (digital or physical) that has a high degree of flexibility
3D scanning camera	3.14	3.5	1.51	0	5	14	4	148	159	Camera that scans a physical object into 3D model/data/data
Stranding machine	2.5	3	1.57	0	5	12	1	162	161	Machine that is used to fix, squeeze or tighten an element
	Rounds 1, 2 and 3							Rk. by		
CONDITIONS (n=23)	μ	Med.	σ	Min.	Max.	n	R1 n	μ	σ	**Definition**
On-site constructability	4.29	4.5	0.83	3	5	14	1	7	40	Feasibility to construct on-site after the off-site digital fabrication
DFAB information involved early	4.17	4	0.94	2	5	12	1	16	66	When digital fabrication information is provided during the design process or before the fabrication process starts
Common Virtual Environment	4.08	4	0.64	3	5	13	6	24	7	A mutually accessible virtual environment that allows multi-disciplinary teams to co-create, coordinate and collaborate
Design-construction integration	4.08	4	0.95	3	5	13	2	25	69	Where the design information and the construction information are integrated
Early contractor involvement	4.08	4	0.95	2	5	13	8	26	70	When the general contractor/digital fabrication trade contractor actively get involved during the design process
Good supervision	4	4	0.88	3	5	14	1	35	53	Condition with good supervision of work during the off-site digital fabrication process and on-site assembly process
Information integration	3.92	4	1.19	1	5	13	3	42	121	Where information from multi-disciplinary teams are integrated
Flexible design	3.79	4	0.8	3	5	14	2	61	36	Where the design has a high degree of flexibility for changes
Appropriate project design delivery models	3.77	4	1.09	2	5	13	1	65	104	Project model(s) for design and delivery which is feasible to deliver project target values
Cost control	3.69	4	1.03	2	5	13	1	82	89	Competence to control or manage costs for the digital fabrication
Common Data Environment	3.67	4	0.78	2	5	12	2	86	25	Mutually accessible virtual environment of database that allows multi-disciplinary teams to access, edit and share data
Immersive VR Environment	3.67	4	0.89	2	5	12	4	87	55	Virutal Reality (VR) environment that provides an immersive experience for collaboration and coordination amongst teams
Building codes for 3D implementation	3.54	3	1.13	1	5	13	1	105	110	Building codes that assist industry to implement technology and workflow involving 3D information
Project Lifecycle Management (PLM)	3.5	4	1.38	0	5	12	1	110	148	Management for handling project(s) as they progress through the typical stages of the project lifecycle
Open BIM	3.46	4	1.51	0	5	13	2	117	160	Collaborative process based on open standards and workflows that allow data sharing with any BIM compatible platform
FM management requirements	3.42	3	1.08	1	5	12	1	123	101	Information and management-related requirements regarding future Facility Management (FM) after construction
On-site adaptable logistics	3.38	4	1.39	1	5	13	1	127	152	Logistics provision is adaptive to real-time on-site situations or requirements
Point cloud simulation	3.38	4	1.39	0	5	13	2	128	153	Provision of visual forecasting simulation using technology that generates point cloud data
Detailed contracting environment	3.31	3	0.63	2	4	13	1	135	5	Environment where contracting requirements and/or potential provisions are described in details
Knowledge transfer	3.08	3	1.12	1	4	13	3	150	108	Provision or environment that facilitates knowledge sharing or exchange amongst multi-disciplinary teams
Human-robot interaction	2.92	3	1.16	1	5	12	2	154	116	Interactive environment or provision that enables coordination between humans and robots
3D scanning provision	2.79	3	1.37	0	5	14	4	160	146	Providing environment or technology to scan in 3D and generate 3D data
Liability waiver	2.55	3	1.37	0	5	11	1	161	147	Legal proposition that can exempts team(s) from legal liability for the specified activities (with acknowledged risks)
	Rounds 1, 2 and 3							Rk. by		
ATTRUBUTES (n=20)	μ	Med.	σ	Min.	Max.	n	R1 n	μ	σ	**Definition**
Customisable	4.15	4	0.55	3	5	13	3	18	2	With the capability for design customisation
Mutual trust and sharing amongst teams	4.14	5	1.03	2	5	14	1	20	90	With trust and the willingness to share information (eg models) or risk/rewards amongst multi-disciplinary teams
Optimisable	4.07	4	0.73	3	5	14	4	30	13	With the capability for architectural/engineering/construction optimisation
Constructable	4	4	0.78	3	5	14	4	36	26	With the capability to construct appropriately and correctly
On-site integrable	4	4	0.78	3	5	14	1	37	27	With the capability to integrate the digitally fabricated system with other systems during the on-site assembly process
Modular	3.93	4	0.62	3	5	14	7	41	4	Attribute where the system or step involves modules as the basis in design/construction
Certainty in cost	3.92	4	1.04	2	5	13	1	43	94	Attribute with certainty regarding the resultant cost of digital fabrication
Knowledge capture	3.85	4	0.99	2	5	13	1	51	79	Attribute where multi-disciplinary knowledge is documented to a certain extent.
2D & BIM integrable	3.83	4	1.11	2	5	12	1	55	106	With the capability to integrate 2D drawings and BIM information (e.g. 3D models)
Risk sharing/agile management	3.83	4	0.58	3	5	12	2	56	3	With the feasibility to share risks amongst teams or provision of agile management (e.g. costs)
Automated in fabrication	3.77	4	1.01	2	5	13	3	66	85	With the fabrication process being operated automatically
Prefabricatable	3.77	4	1.01	2	5	13	1	67	86	With the capability to fabricate in advance before on-site assembly
Precise design information	3.77	3	0.93	3	5	13	3	68	63	Design information is accurate and contains sufficient information of the design intents
Flexible	3.75	4	0.87	2	5	12	2	72	50	With the capability to adapt to changes
Integrated design-build	3.75	4	1.22	2	5	12	1	73	127	With organisational integration in the design and construction process (e.g. Design-Build model)
Fulfil legal & regulatory requirements	3.62	4	0.96	2	5	13	1	93	72	With the compatibility to satisfy the legal/contractual and regulatory requirements (e.g. building codes)
Inclusive	3.58	3	1.08	2	5	12	1	99	102	With the feasibility or intention to include all actors or actants under a general situation
On schedule	3.54	4	0.97	2	5	13	1	106	73	With the feasibility to assure plans or activities proceed according to a defined schedule
Systemic Innovation	3.45	3	0.52	3	4	11	1	121	1	Innovation(s) that cuts across traditional discipline and supply chain boundaries and fosters system integration
Incentive	3.42	4	0.79	2	4	12	1	124	32	With the impact that motivates or encourages team(s) to achieve defined values

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PROCESSES (n=22)	Rounds 1, 2 and 3 μ	Med.	σ	Min.	Max.	n	R1 n	Rk. by μ	Rk. by σ	Definition
Architectural design optimisation	4.21	4	0.8	3	5	14	6	12	37	Process to optimise the architectural design (eg geometry)
Integration within packages	4.14	4	0.77	3	5	14	1	21	23	Process to integrate various system packages during the construction process
DFAB process optimisation	4.08	4	0.79	3	5	12	5	27	33	Process to optimise the digital fabrication process (eg 3D printing path)
Engineering design optimisation	4.08	4	0.67	3	5	12	1	28	9	Process to optimise the engineering design (eg structural/MEP performance)
Construction process optimisation	4.07	4	0.73	3	5	14	1	31	14	Process to optimise the performance (eg efficiency) during the construction process
Digital prefabrication	3.92	4	0.9	3	5	12	1	44	57	Prefabrication process undertaken digitally
Value Engineering	3.92	3	1	3	5	12	2	45	82	Process to improve the values (eg cost-effectiveness) of the outcomes by examination of design
Review of shop drawings	3.86	4	0.66	3	5	14	1	50	8	Process to review shop drawings for digitally fabricating the system(s)
Modularisation	3.79	4	0.8	3	5	14	3	62	38	Process to form modules
Post-rationalisation	3.77	3	0.93	3	5	13	8	69	64	Optimisation process where a detailed design is further rationalised to suit the constructability
Lean fabrication	3.75	3	1.29	1	5	12	2	74	136	Fabrication process adopting lean management principles (e.g. pull-planning)
Performance test	3.73	4	1.1	2	5	11	1	77	105	Process to test the performance (e.g. structual performance) of the system(s)
On-site modification	3.69	4	0.75	3	5	13	2	83	17	Process to modify the system(s) on-site after the off-site digital fabrication
Post-test refinement	3.64	4	0.92	2	5	11	1	90	61	Refinement process of the system/system performance after a test
4D simulation	3.5	3	1.24	1	5	12	1	111	128	Simulation process for visual forecasting that considers time/schedule
4D simulation in BIM	3.5	3	1.38	0	5	12	1	112	149	Simulation process for visual forecasting on a BIM-based platform that considers time/schedule
Customisation	3.5	4	0.85	2	5	14	2	113	47	Design development process to adjust the design to suit a defined requirement/request/function
Performance optimisation	3.5	3	1	2	5	12	1	114	83	Process to optimise the system performance (e.g. process's CO2 emission)
Parametric design	3.46	3	0.97	2	5	13	1	118	74	Design process with features being shaped according to algorithmic processes
Prefabrication	3.42	3	0.67	3	5	12	5	125	10	Fabrication process that happens in a factory or other manufacturing site other than the construction site
Industrialisation	3.38	3	1.39	1	5	13	1	129	154	Process that commonly includes modularisation, prefabrication, preassembly and mass production
Standardisation	3.38	3	1.26	1	5	13	2	130	130	Process of making a system/workflow conform to a certain standard of rule/definition

ARTEFACTS (n=14)	Rounds 1, 2 and 3 μ	Med.	σ	Min.	Max.	n	R1 n	Rk. by μ	Rk. by σ	Definition
Precise 3D BIM construction model	4.29	4.5	0.83	3	5	14	1	8	41	Output of precise BIM-based model(s) for construction or generated during the construction process
Integrated construction data	4.25	4	0.75	3	5	12	1	10	18	Output of data for construction that comprises those from multi-disciplinary teams
Physical mock-up of process	4.23	4	0.73	3	5	13	4	11	15	Output of physical mock-up simulation of the digital fabrication process
Integrated BIM models	4.21	4.5	0.89	3	5	14	5	13	56	Output of BIM-based model(s) that comprises those from multi-disciplinary teams
Precise 3D BIM design model	4.21	4	0.7	3	5	14	2	14	12	Output of precise BIM-based model(s) in 3D comprises the design intents or generated during the design process
Integrated 3D models	4.07	4	0.83	3	5	14	6	32	42	Output of model(s) in 3D that comprises those from multi-disciplinary teams
Integrated 2D dwgs and 3D models	4	4	0.78	3	5	14	4	38	28	Output of drawing(s) in 2D that matches the model(s) in 3D
Fabrication specification	3.92	4	0.76	3	5	13	2	46	21	Output of specification including information about the digital fabrication process
Automated tracking systems	3.91	4	0.94	2	5	11	2	49	67	Output of automated systems that can track the progress of the digital fabrication process
Detailed 2D drawings	3.79	4	0.97	2	5	14	6	63	75	Output of 2D drawings with detailed information (e.g. interfaces, material specification)
Quantity takeoff	3.64	4	0.84	2	5	14	1	91	45	Output of detailed measurement(s) of materials and labours needed to complete a process in a project
Virtual mock-up of process	3.62	4	1.04	1	5	13	6	94	95	Output of virtual mock-up simulation of the digital fabrication process
Configurator/kit-of-parts	3.5	3.5	1	2	5	12	5	115	84	Output of arrangement of engineered parts to create a variety of families of related objects
Point cloud files	3.08	3	0.76	2	4	13	1	151	22	Output of data or visualisation from the point cloud simulation

VALUES (n=25)	Rounds 1, 2 and 3 μ	Med.	σ	Min.	Max.	n	R1 n	Rk. by μ	Rk. by σ	Definition
Reduce errors	4.36	4	0.63	3	5	14	4	5	6	Reward of error reduction in manufacture or assembly during the construction process
Improve quality/performance	4.29	4.5	0.91	2	5	14	6	9	60	Reward of quality improvement in construction and/or performance (e.g. in structure) of the products
Improve design communication	4.07	4.5	1.14	1	5	14	2	33	113	Reward of better communication amongst multi-disciplinary teams during the design process
Reduce uncertainty	4	4	1.18	2	5	14	4	39	120	Reward of uncertainty reduction during the digital fabrication process
Improve capability	3.77	4	1.17	2	5	13	2	70	119	Reward of capability (e.g. competence of design and digital fabrication) of the teams
Reduce construction complexity	3.71	4	1.33	1	5	14	3	81	138	Reward of construction complexity (e.g. manufacturing steps) reduction
Improve human skills	3.64	4	0.93	2	5	14	2	92	65	Positive improvement in human skills regarding construction and digital fabrication
Increase design complexity	3.62	4	1.26	1	5	13	4	95	131	Positive impact on encouraging development and fabrication of highly complex design
Reduce conflicts through DFAB	3.62	4	1.19	1	5	13	2	96	122	Positive impact on reducing conflicts (e.g. system interfaces) during the fabrication process
Reduce time/increase efficiency	3.57	3.5	1.28	2	5	14	5	103	135	Positive improvement in process efficiency and reduction of time spent on fabrication
Boost customisation	3.54	4	0.97	2	5	13	1	107	76	Positive impact on fostering design customisation to suit defined requirements
Enable modularity design	3.54	4	0.97	2	5	13	1	108	77	Positive impact on facilitating modularity in design development
Reduce overall cost	3.5	3.5	1.34	1	5	14	7	116	140	Positive impact on reducing the overall project costs (including costs in design and construction)
Boost creativity	3.46	4	1.2	2	5	13	1	119	125	Positive impact on foster creativity of the project team(s)
Reduce interface cost	3.46	3	0.78	2	5	13	1	120	29	Positive impact on reducing costs in particular for system interface (e.g. between two systems)
Knowledge transfer	3.38	4	1.19	1	5	13	2	131	123	Positive impact on facilitating knowledge sharing or exchange amongst multi-disciplinary teams
Enable automation	3.36	4	1.29	1	5	11	1	133	137	Positive impact on facilitating the adoption of automation in construction
Enable sustainability performance	3.31	3	1.03	1	5	13	3	136	91	Positive impact on facilitating sustainability performance (e.g. reuse of materials)
Boost industrialisation	3.23	3	1.36	1	5	13	1	143	143	Positive impact on fostering industrialisation processes (e.g. modularisation)
Controllable cost	3.23	3	0.73	2	4	13	3	144	16	Positive impact on ensuring that cost(s) are under controlled and monitored
Reduce assembly costs	3.21	3	1.42	1	5	14	1	145	155	Positive impact on reducing costs during the assembly process of a system
Increase return of investment	3.17	3	1.27	1	5	12	1	146	133	Positive impact on the return of investement from profits, cost reduction etc.
Controllable schedule	3	3	1.08	1	5	13	2	152	103	Positive impact on ensuring that the process schedules are under controlled and monitored
Reduce human involvement	2.92	3	1.38	0	5	13	1	155	150	Positive impact on reducing manpower to actively work on the fabrication process
Increase reputation	2.92	3	0.79	2	4	12	1	156	34	Positive improvement on the reputation regarding digitalisation of an organisation/team

RISKS (n=28)	Rounds 1, 2 and 3 μ	Med.	σ	Min.	Max.	n	R1 n	Rk. by μ	Rk. by σ	Definition
Design/BIM and on-site misalignment	4.17	4	1.03	2	5	12	3	17	92	Risk where the design information or BIM information does not match the information on-site
Constructability uncertainty	4.15	4	0.8	3	5	13	1	19	39	Risk with uncertain feasibility in construction (manufacture and/or assembly)
Lack of skilled labour	4.08	4	0.95	2	5	13	3	29	71	Risk where there is insufficient skilled labour to conduct the digital fabrication work
Expectation misalignment	3.92	4	0.86	3	5	13	2	47	48	Risk where the expectations amongst teams are not matching
DFAB knowledge not integrated	3.92	4	0.79	3	5	12	2	48	35	Risk when digital fabrication knowledge is not integrated in design
Errors in platforms/formats exchange	3.85	4	1.07	2	5	13	1	52	97	Risk with errors within the platform(s) or during format exchange within platforms
Increase overall cost	3.85	4	1.07	2	5	13	2	53	98	Risk of an increase in the overall costs during the design and construction process
Workforce training is required	3.85	4	0.99	2	5	13	3	54	80	Risk when training of workers is required to conduct digital fabrication
Discrete understandings	3.83	4	1.03	2	5	12	2	57	93	Risk when there the understandings/knowledge amongst teams are fragmented (i.e. not integrated)
Documentation misalignment	3.83	4	0.83	2	5	12	2	58	43	Risk when the design documentation does not match the construction documentation (outputs)
High dependency upon BIM	3.75	4	0.87	3	5	12	2	75	51	Risk of over depending on BIM platform or BIM usage
High dependency upon supply-chain	3.75	4	0.87	2	5	12	1	76	52	Risk of over depending on the supply chain during the construction process
Increase design cost	3.69	4	0.75	3	5	13	1	84	19	Risk of increase in design costs (e.g. fee to hire DFAB design coordinator)
Lengthen design process	3.69	4	0.75	3	5	13	2	85	20	Risk of extending the duration of the design process (e.g. extra time is needed for design coordination)
DFAB process uncertainty	3.67	4	0.78	2	5	12	1	88	30	Risk with uncertain feasibility during the digital fabrication process
Increase workforce	3.62	3	0.77	3	5	13	1	97	24	Risk of an increase in manpower to work on a certain task
Digital inconsistency	3.58	4	0.9	2	5	12	1	100	58	Risk of the digital information (e.g. from different teams) are not consistent)
High dependency upon DFAB skills	3.58	4	1.16	1	5	12	3	101	117	Risk of the team(s) depends too much on the requirements of digital fabrication skills
Lack of suitable machinery	3.38	4	1.26	1	5	13	1	132	132	Risk that there is no suitable machinery to implement digital fabrication
Lack of suitable materials	3.31	3	1.38	1	5	13	1	137	151	Risk of that there is no suitable materials for implementing digital fabrication
Skills & knowledge misalignment	3.29	3	1.07	1	5	14	2	138	99	Risk where the skills and knowledge amongst teams are not aligned
High dependency upon electricity systems	3.25	3	1.14	1	5	12	1	139	114	Risk of the team(s) depends too much on electricity consumption
Sceptical attitude towards digital design	3.25	3	1.36	1	5	12	1	140	144	Team(s)' sceptical attitude towards the adoption of digital design
Sceptical attitude towards DFAB	3.25	3	1.36	1	5	12	3	141	145	Team(s)' sceptical attitude towards the adoption of digital fabrication
Cyber security	3	3	1.48	1	5	12	2	153	158	Risk of cyber attack in systems, networks, programs, devices and data
Building codes not suit DFAB	2.92	3	1.66	0	5	13	1	157	163	Risk of the buildings codes do not align to the situation in digital fabrication
Limited market competition/Monopoly	2.92	3	1.16	1	5	12	1	158	118	Risk of monopoly in delivering the digital fabrication in the market
Degrade of human skills	2.5	2.5	1.57	0	5	12	1	163	162	Risk of demoting human's development of skills and knowledge