Sustainability and Resiliency Efforts for the Roofing Industry

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Objectives of the study

- Identify the current state of various sustainability and resiliency efforts in the roofing industry.
- To develop and implement professional development training modules to educate the roofing industry professionals regarding roofing sustainability and resiliency.

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Study Approach

1. Literature Review → Survey Design → Pilot Study → Data Analysis → Survey Questionnaire Refinement
2. Survey Distribution → Survey Data Collection → Data Preprocessing → Descriptive and Statistical Data analysis → Survey Results
3. Interviews with M/D/Cs → Interview analysis → Interview Findings → Final report → Curriculum

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Literature Review

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Creating keyword combinations and exploring in Databases

KEYWORD COMBINATION LIST
(sustain* OR resilien*) AND (building construction) AND (United States)
(sustain* OR resilien*) AND (roof*)
(sustain* OR resilien*) AND (manufacturing) AND (roof*)
(sustain* OR resilien*) AND (roof*) AND (construction) OR (material supply chain)
(sustain* OR resilien*) AND (architectural design) AND (roof*)
(sustain* OR resilien*) AND (built environment) AND (roof*)
(sustain* OR resilien*) AND (construction industry) AND (roof*)
(sustain* OR resilien*) AND (environmental impacts) AND (roof*)
(sustain* OR resilien*) AND (building energy efficiency)
(sustain* OR resilien*) AND (adaptive design) AND (building roof* system)
(sustain* OR resilien*) AND (Distributor)
(sustain* OR resilien*) AND (Distributor) AND (Building Construction)
(sustain* OR resilien*) AND (Distributor) AND (roof*)
(sustain* OR resilien*) AND (Manufacturer) AND (Building Construction)
(sustain* OR resilien*) AND (Manufacturer) AND (roof*)

DATABASES
EBSCOhost (Academic Seach Complete, Applied Science and Technology, Avery Index to Architectural Periodicals, GreenFILE)
Engineering Village (Compendex, GeoRef, INSPEC & Knovel)
ASCE Library
IEEE Xplore
Technology Collection (ProQuest)
ASME Digital Library
BuildingGreen Suite
JSTOR
Web of Science Core Collection (includes ScienceDirect)
ICONDA (Construction Database)

100,000+ Peer-reviewed articles

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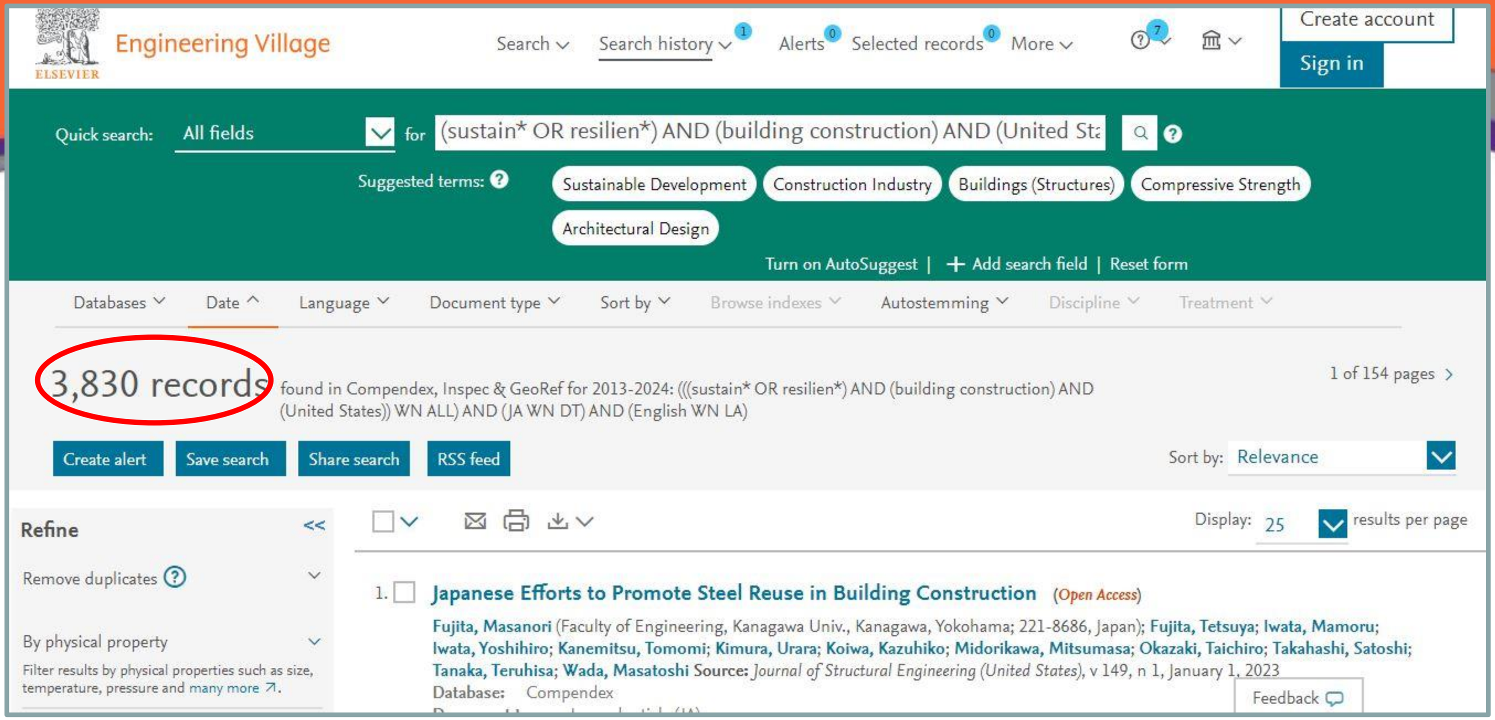
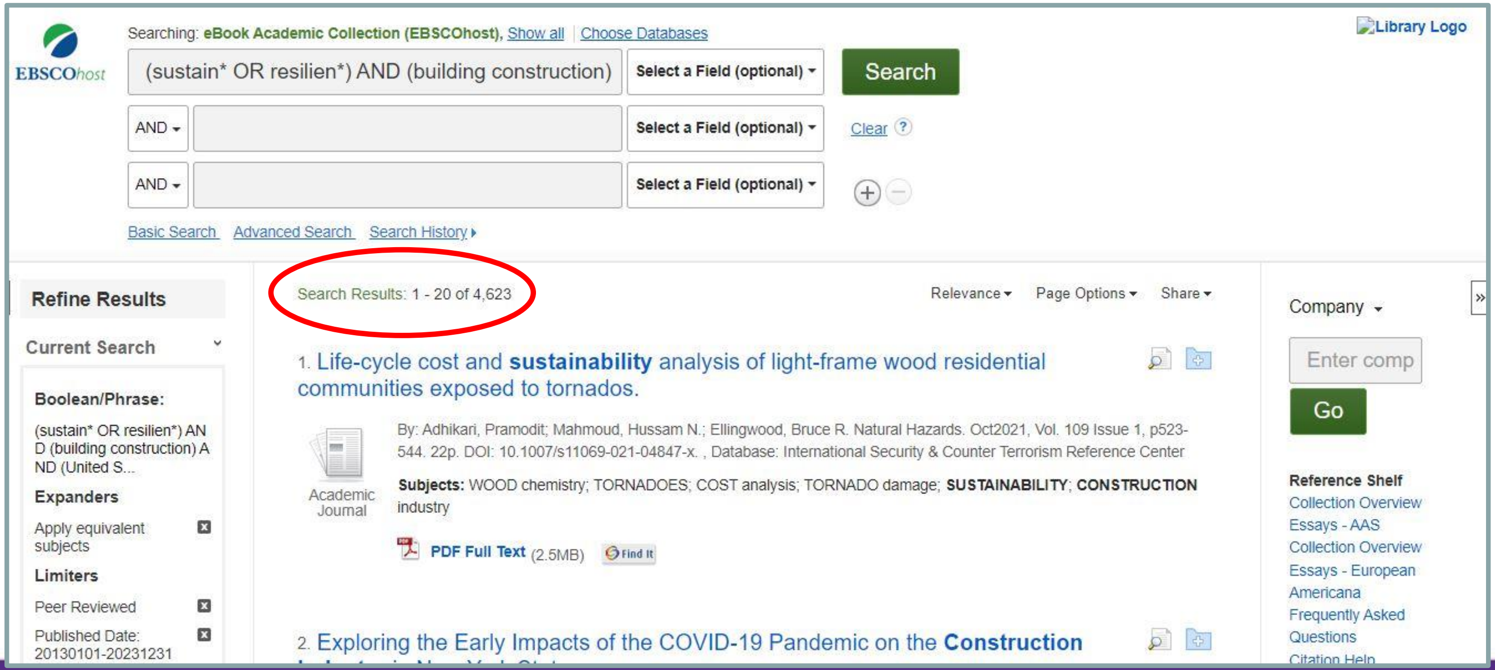
Examples of articles explored in different databases with different keyword combinations





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Steps followed while narrowing down the research

- 100,000+ PEER REVIEWED ARTICLES
  - 3,613 RELEVANT ARTICLES
    - 243 SELECTED ARTICLES
      - 78- SUSTAINABILITY FACTORS
      - 28- RESILIENCY FACTORS

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Example of factors extraction from articles

Durability, Resilience and Sustainability in the Building Rehabilitation Process

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Abstract. Where buildings are concerned, the term "sustainability" has been used for more than 30 years. It represents a process of designing, constructing and operating the building considering its environmental impact. A year after the major nuclear plant catastrophe from Chernobyl, the Brundtland Report defined sustainability as the actions that meet "the needs of the present without compromising the ability of future generations to meet their own needs". A different disaster, a natural one – the Katrina hurricane – led, two decades later, to the addition of another building characteristic: "resilience". It represents the capacity of a system to adapt after a shock. "Durability" may refer to different issues: the building materials, the building structure, its functionality or aesthetics. The more durable a building is - the more it lasts - the less it affects the environment. The more it lasts, the more resilient it is (as it withstands different types of stress). Technical durability, provided by building materials and structures,

Sustainability factor:
Environmental Impact

Resiliency factors:
Adaptive
Durability

Survey Responses

Participant's Background

Manufacturers

#	Annual Sales	No. of employees	Years of Experience
1	$35 M	60	25
2	$250 M	140	6
3	$30 M	40	24
4	$45 M	300	1
5	$75 M	102	40+
6	$675 M	400	20
7	$550 M	600	28
8	$250 M	250	15
9	$300 M	500	11
10	N/A	1000+	37

Distributors

#	Annual Sales	No. of employees	Years of Experience
1	$20 B	60	25
2	$9 B	140	6
3	$10 B	40	24

Consultants

#	Annual Sales	No. of employees	Years of Experience
1	$2.2M	13	41
2	$20 M	120	35

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Participant’s Background

Contractors

#	Annual Sales	No. of employees	Years of Experience
1	$25 M	50	19
2	$500 M+	5000 plus	30+
3	$30 M+	50	20
4	$15 M+	60	30
5	$93 M	250	20
6	$23 M	100	7
7	$15 M	50	55
8	$170 M	260	55
9	$17 M	50	25
10	$30 M+	130	38
11	$50 M	200+	40
12	$24 M	58	46
13	$12 M	28	44
14	$165 M	200	28
15	$40 M	82	93
16	$200 M	750	40

#	Annual Sales	No. of employees	Years of Experience
16	$37 M	130	55
17	$25 - 30 M	110	30+
18	$12 M	65	32
19	$60 M	175	20
20	$10 M	55	44
21	$25 M	60	45
22	$15 M	65 - 80	40
23	$25 M	63	42
24	$5 M	45	30
25	$42.5 M	256	79
26	$106 M	413	23
27	$15 M	65 - 80	40
28	$8 M	34	40
29	$31,500	160	40
30	$35 M	58	20
31	$19 M	90	26
32	$42 M	283	34
33	$75 M	275	30

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Statistical Tests

Variable view and Data view

Search application

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Category_Energy_And_Atmosphere	Numeric	8	0		{1, Heatin...	None	15	Right	Nominal	Input
2	Category_Indoor_Environment_Quality	Numeric	8	0		{1, Therm...	None	12	Right	Nominal	Input
3	Category_Innovation	Numeric	8	0		{1, Implem...	None	8	Right	Nominal	Input
4	Category_Integrated_Planning	Numeric	8	0		{1, Green ...	None	8	Right	Nominal	Input
5	Category_Location_And_Transportation	Numeric	8	0		{1, Distanc...	None	8	Right	Nominal	Input
6	Category_Materials_And_Resources	Numeric	8	0		{1, Reduci...	None	8	Right	Nominal	Input
7	Category_Sustainable_Sites	Numeric	8	0		{1, Equip...	None	8	Right	Nominal	Input
8	Category_Other	Numeric	8	0		{1, Demoli...	None	8	Right	Nominal	Input
9	Category_Str_And_Environmental_Res	Numeric	8	0		{1, Long s...	None	8	Right	Nominal	Input
10	Category_Functional_And_Operational	Numeric	8	0		{1, Retain ...	None	8	Right	Nominal	Input
11	Category_Preparedness_And_Response	Numeric	8	0		{1, Prepar...	None	8	Right	Nominal	Input
12	Energy_and_Atm_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
13	IEQ_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
14	INN_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
15	IPPD_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
16	LT_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
17	MR_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
18	SS_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
19	Other_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
20	SER_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
21	FOR_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input
22	PRR_Responses	Numeric	8	0		{1, Not Sig...	None	8	Right	Ordinal	Input

Search application

Visible: 56 of 56 Variables

	Respondents	Energy_Heating_and_Col	Energy_Renewable	Energy_Conservation	Energy_Greenhousegas	IEQ_Thermal_Insulation	IEQ_Thermal_Radiation	IEQ_Solar_Reflectance	IEQ_Thermal_Absorption	IEQ_Thermal_Transmitti..	IEQ_Natural_Daylight	IEQ_Blocking_Unwanted	IEQ_Reducing_Sound	INN_New_Products	INN_New_Process	IPPD_Green_Construction	IPPD_Green_Retrofitting	LT_Raw_to_Manufacturing
1	1	1	1	1	1	4	3	1	1	1	1	1	1	1	1	1	1	1
2	1	5	2	5	1	4	4	5	4	2	4	3	1	3	4	2	2	1
3	1	4	5	4	4	4	4	4	4	4	3	3	4	3	4	3	3	4
4	1	3	3	4	4	3	3	4	4	3	5	2	1	3	4	3	2	2
5	1	4	3	4	4	4	4	4	4	4	4	4	2	4	4	3	3	4
6	1	4	4	4	3	4	4	4	4	4	4	4	4	3	4	4	4	4
7	1	3	3	3	3	3	3	3	3	3	1	1	1	3	3	3	3	3
8	1	4	2	4	4	5	5	5	5	5	2	2	2	1	5	1	1	4
9	1	4	3	3	2	4	2	2	2	2	1	1	2	3	4	1	1	1
10	1	3	2	3	2	4	2	3	3	2	2	2	2	1	2	3	3	2
11	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1
12	1	3	2	3	3	3	3	4	3	3	1	1	1	1	3	5	5	4
13	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	5	1
14	1	4	3	4	4	4	4	2	4	4	4	4	4	4	4	5	5	3
15	1	2	2	2	2	1	1	1	1	1	1	1	2	2	2	2	2	1
16	1	3	4	2	2	5	3	4	4	3	3	4	2	2	4	4	3	1
17	1	3	4	4	5	4	5	3	4	3	4	5	5	3	3	4	5	5
18	1	4	1	4	1	5	4	4	4	2	4	2	3	2	3	2	2	3
19	1	3	1	2	1	3	1	1	2	2	2	2	1	1	2	1	1	1
20	1	5	5	5	3	5	4	4	4	4	3	2	2	4	4	1	3	2
21	1	5	4	4	3	5	4	4	3	3	2	2	2	2	4	4	4	1
22	1	4	4	4	4	5	4	5	4	4	4	4	3	2	2	5	4	4
23	1	5	1	3	1	5	4	4	3	3	1	1	1	1	3	2	2	1
24	1	4	1	4	1	5	3	3	2	2	5	1	1	3	3	2	2	1
25	1	4	2	3	3	4	4	2	3	4	4	3	3	3	4	2	2	3
26	1	3	3	3	3	4	3	3	3	3	3	3	3	4	5	2	2	2

Output

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distribution of Energy_and_Atm_Responses is the same across categories of Category_Energy_And_Atmosphere.	Independent-Samples Kruskal-Wallis Test	.032	Reject the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

Pairwise Comparisons of Category_Energy_And_Atmosphere

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Total_greenhouse_gas_emissions-Renewable_energy	1.750	4.925	.355	.722	1.000
Total_greenhouse_gas_emissions-Heating_and_cooling_load_req	9.000	4.925	1.827	.068	.406
Total_greenhouse_gas_emissions-Energy_conservation_techniques	12.650	4.925	2.568	.010	.061
Renewable_energy-Heating_and_cooling_load_req	7.250	4.925	1.472	.141	.846
Renewable_energy-Energy_conservation_techniques	-10.900	4.925	-2.213	.027	.161
Heating_and_cooling_load_req-Energy_conservation_techniques	-3.650	4.925	-.741	.459	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

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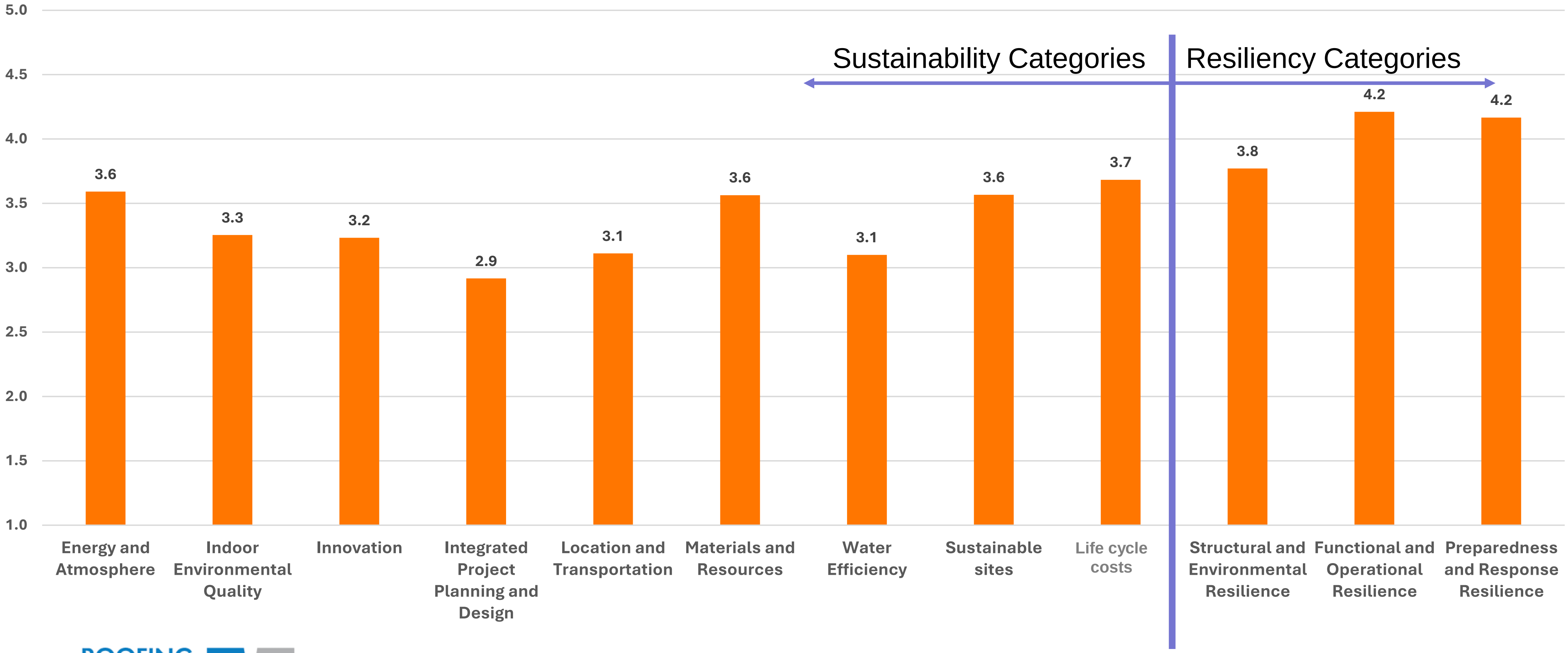
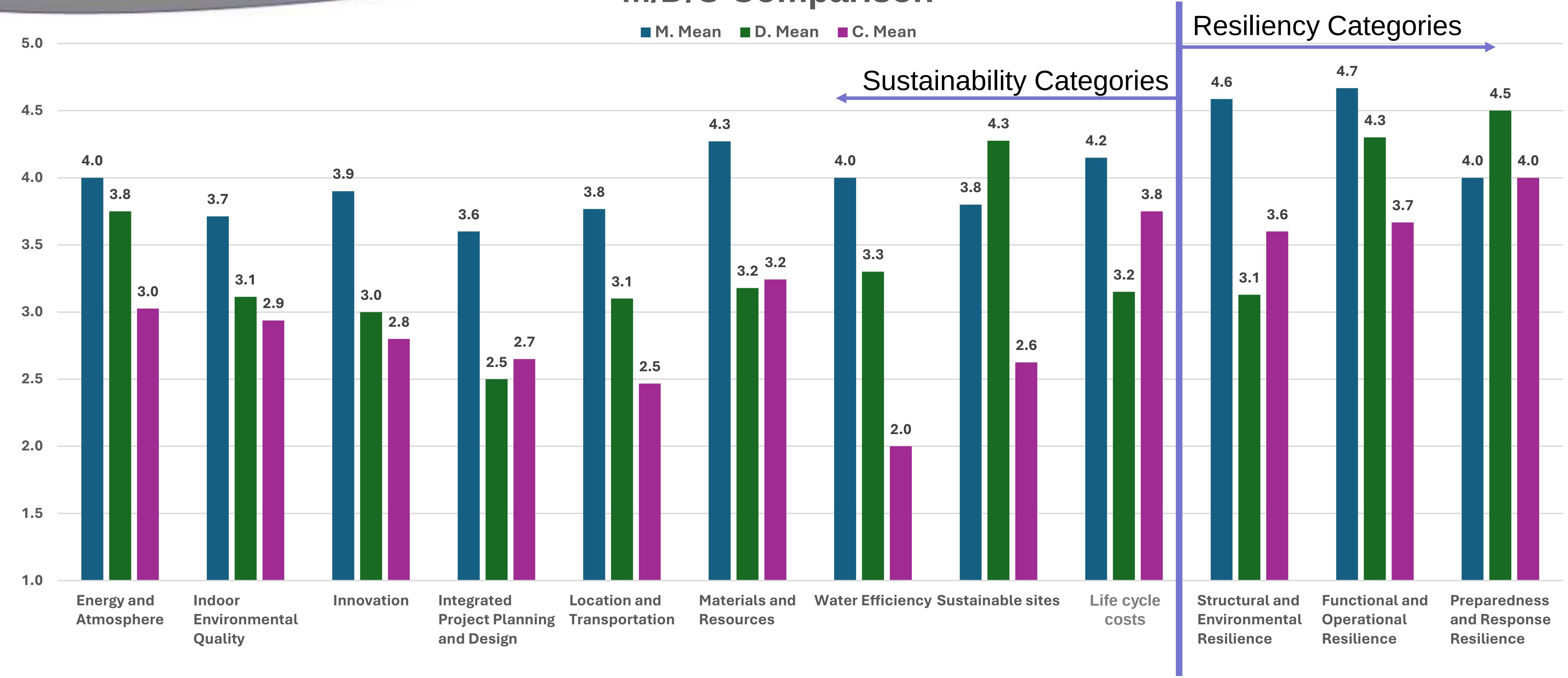
Overall Responses for Sustainability and Resiliency



Note: 1- Not Significant, 2- Slightly Significant, 3- Neutral, 4- Significant, 5- Very Significant

M/D/C Comparison



Note: 1- Not Significant, 2- Slightly Significant, 3- Neutral, 4- Significant, 5- Very Significant

Comparison of top factors between M/D/C

Manufacturers	Mean Values	Distributors	Mean Values	Contractors	Mean Values
Long Service Life	5.0	Equipment emission	4.7	Long Service Life	4.3
Retain critical functions	5.0	Transportation emission	4.7	Resistance to external forces	4.2
Recover rapidly	5.0	Preparation for major disruptions	4.6	Lifecycle of materials	4.1
Lifecycle of materials	4.9	Ability to adapt	4.6	Ability to absorb external stresses	4.1
Low maintenance	4.8	Retain critical functions	4.3	Thermal insulation	4.0

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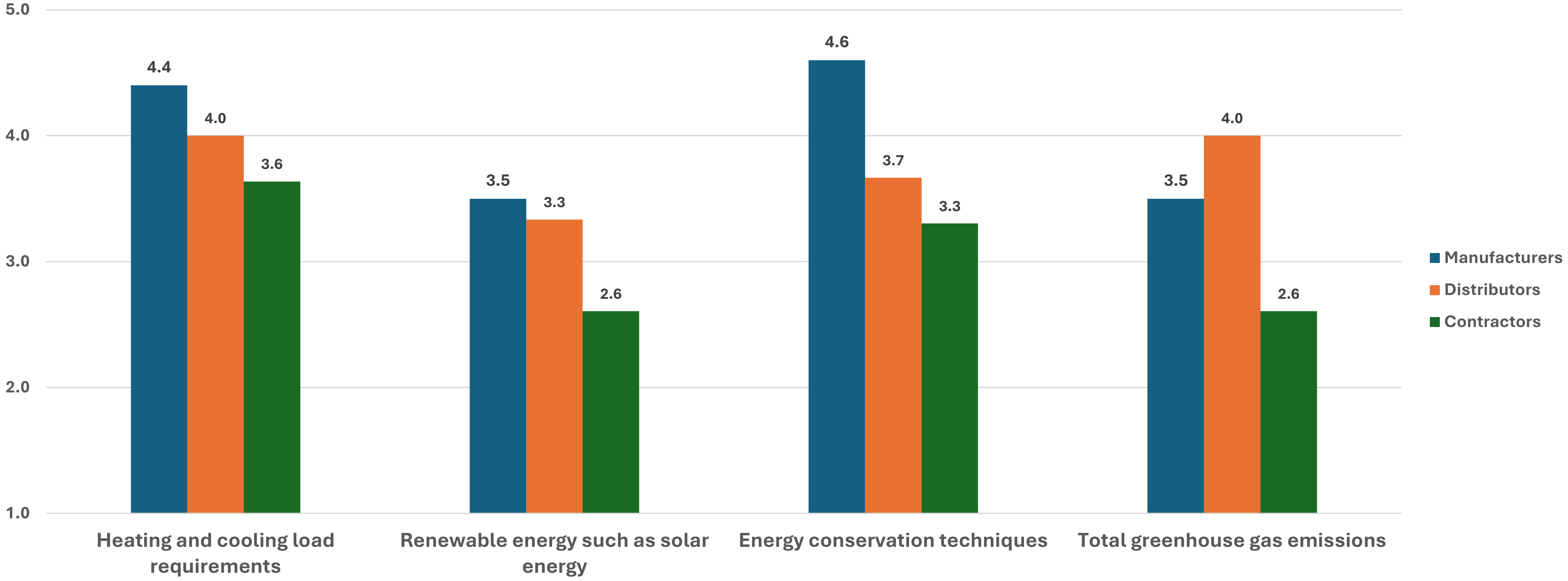
Sustainability Factor Comparison (M/D/C)

Mean Responses on LEED Category 1: Energy and atmosphere



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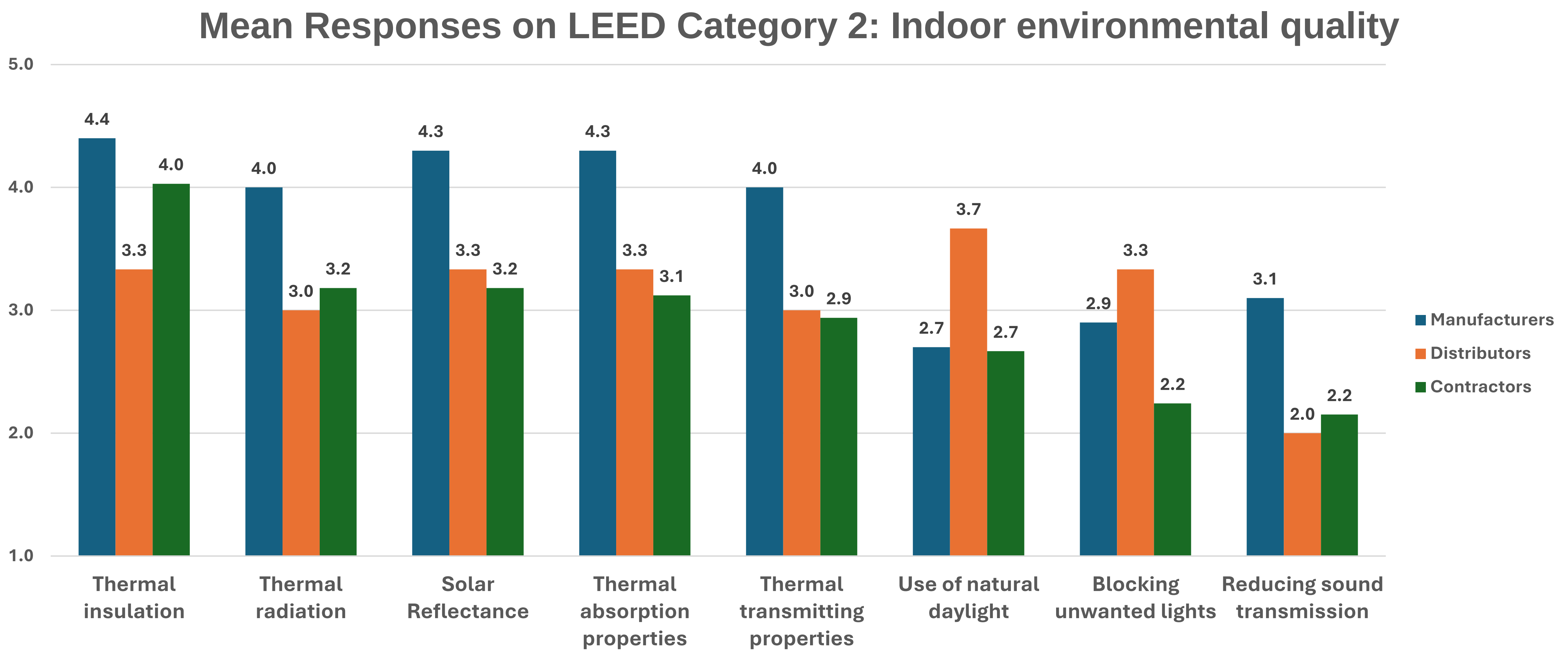

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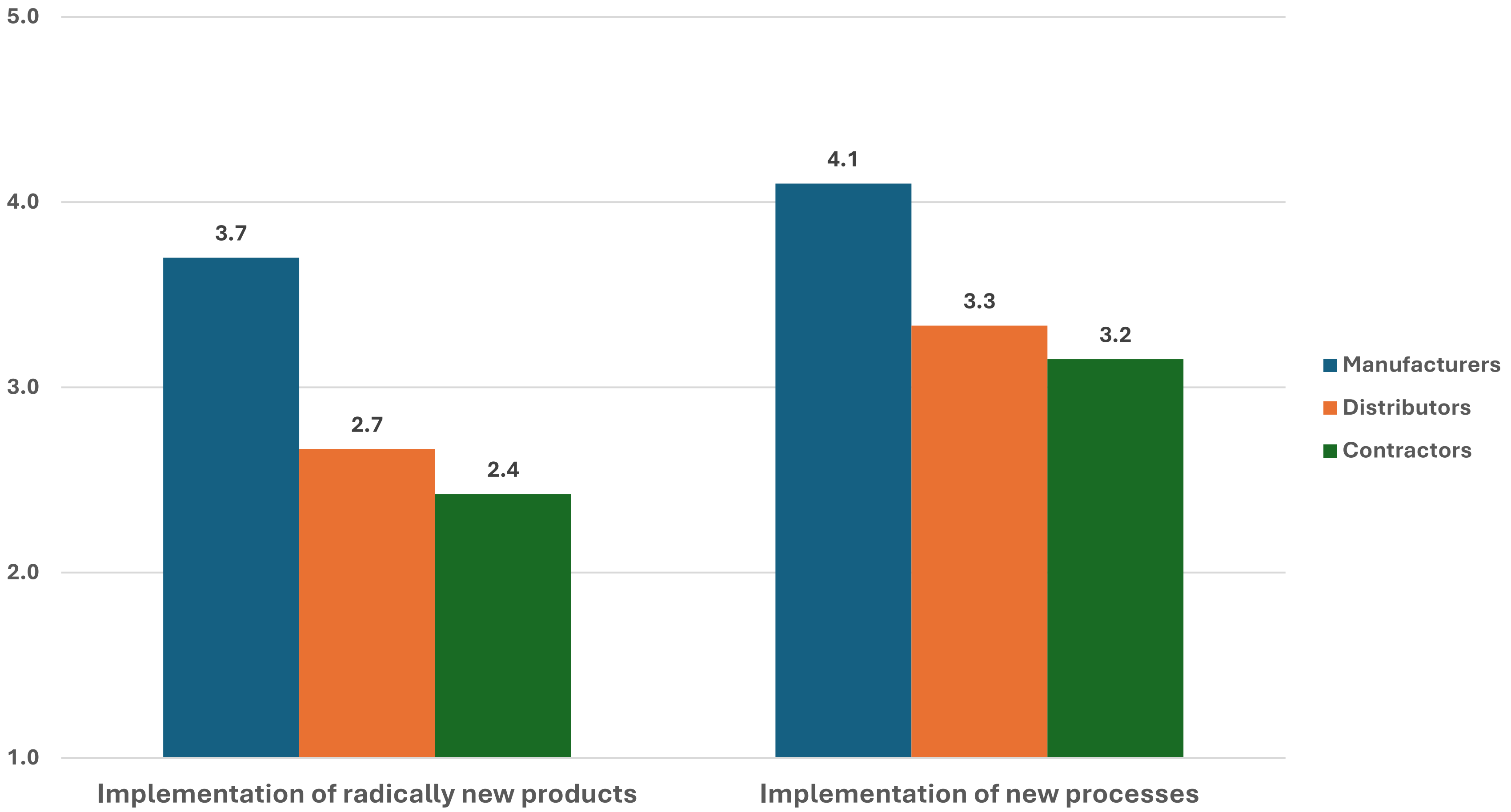
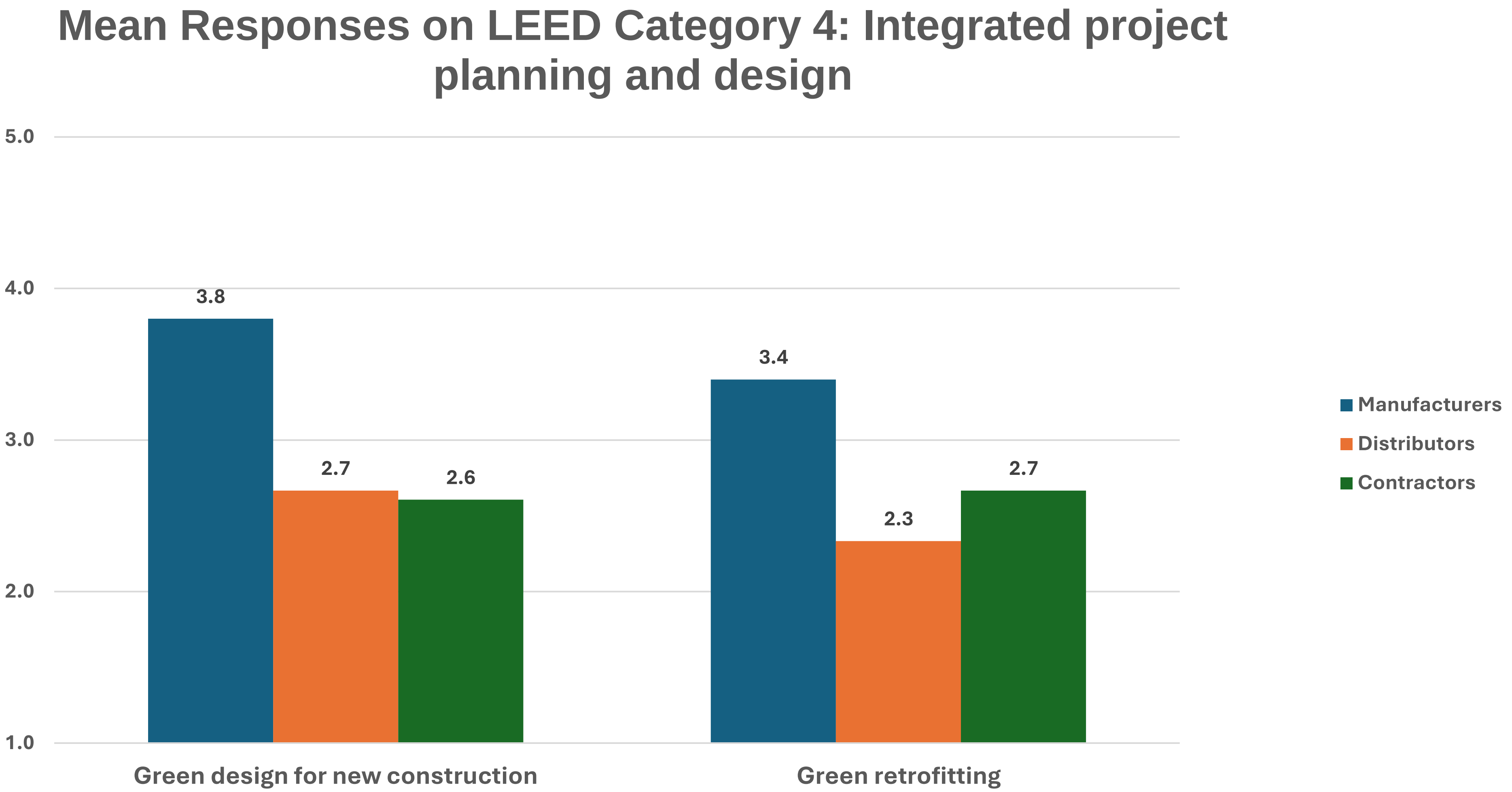
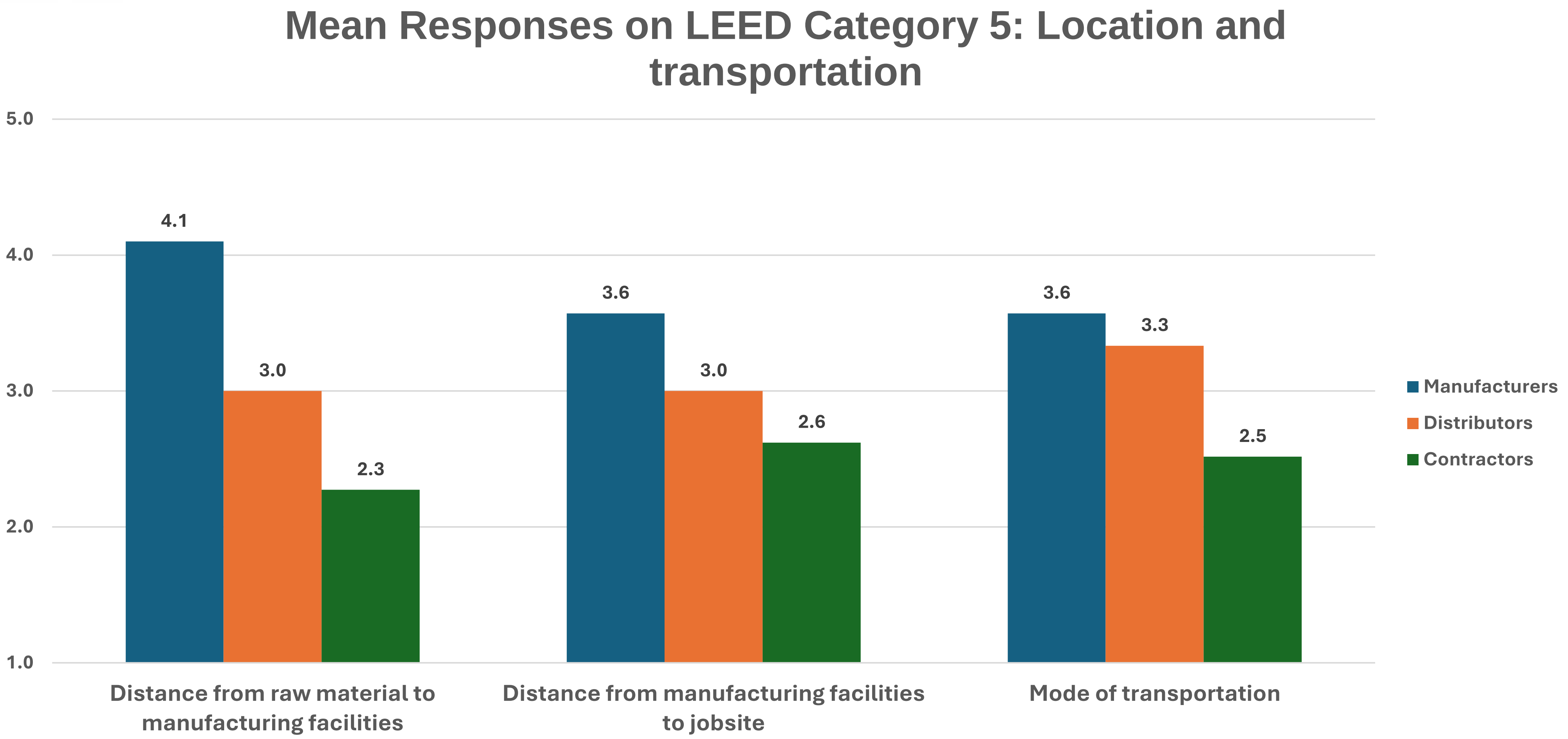
Mean Responses on LEED Category 3: Innovation

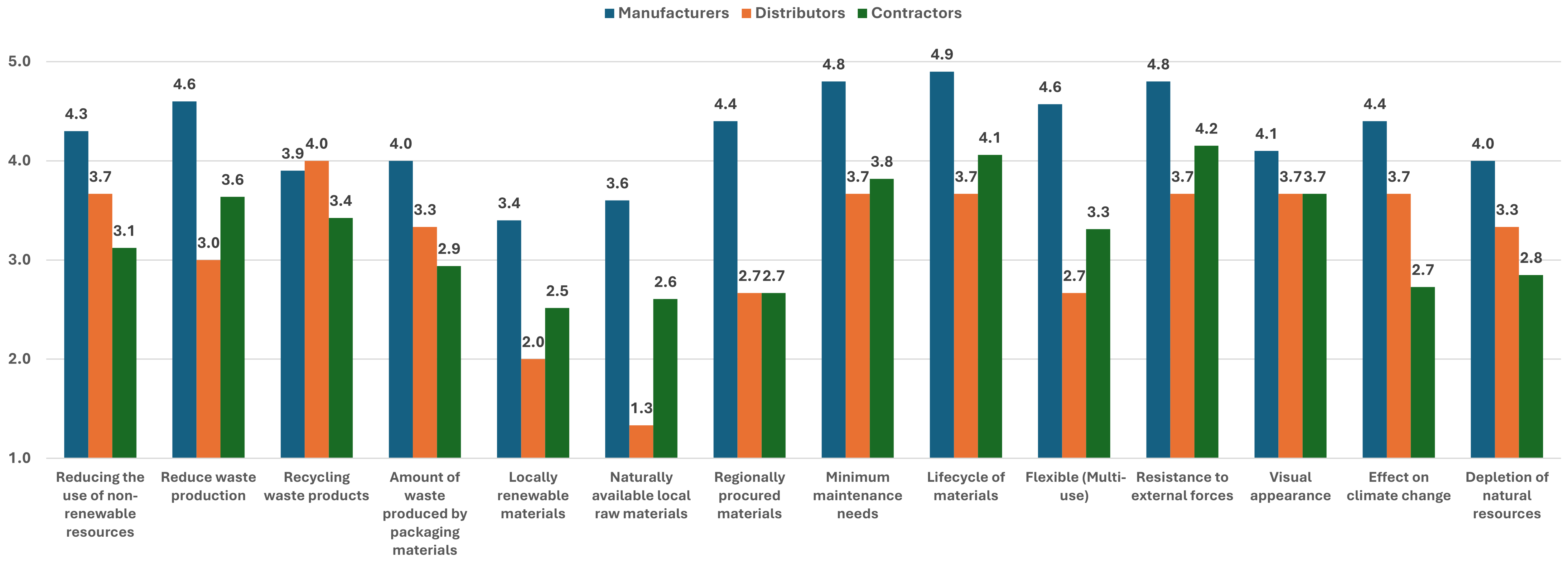




Mean Responses on LEED Category 4: Integrated project planning and design
5.0
4.0
3.0
2.0
1.0
3.8
2.7
2.6
3.4
2.3
2.7
Green design for new construction
Green retrofitting
Manufacturers
Distributors
Contractors


Mean Responses on LEED Category 5: Location and transportation
5.0
4.0
3.0
2.0
1.0
4.1
3.0
2.3
3.6
3.0
2.6
3.6
3.3
2.5
Distance from raw material to manufacturing facilities
Distance from manufacturing facilities to jobsite
Mode of transportation
Manufacturers
Distributors
Contractors

Mean Responses on LEED Category 6: Materials and Resources



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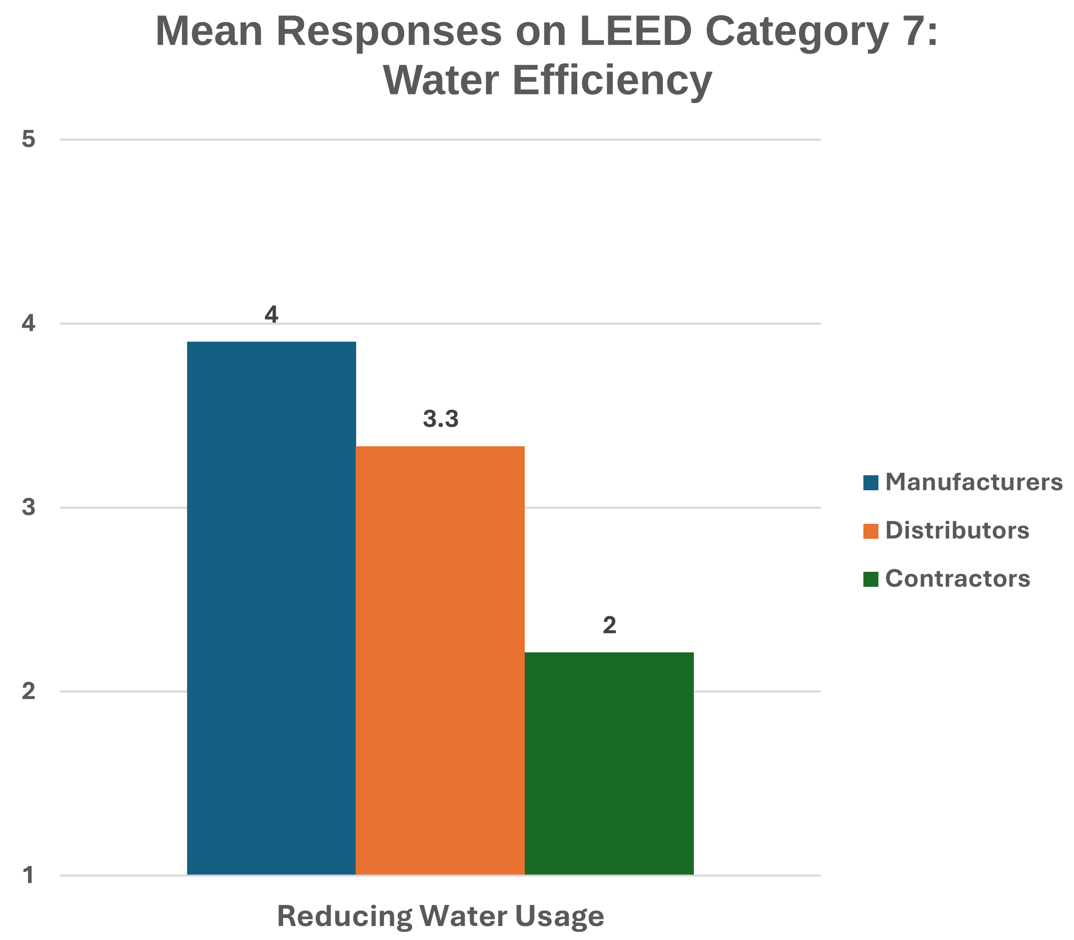
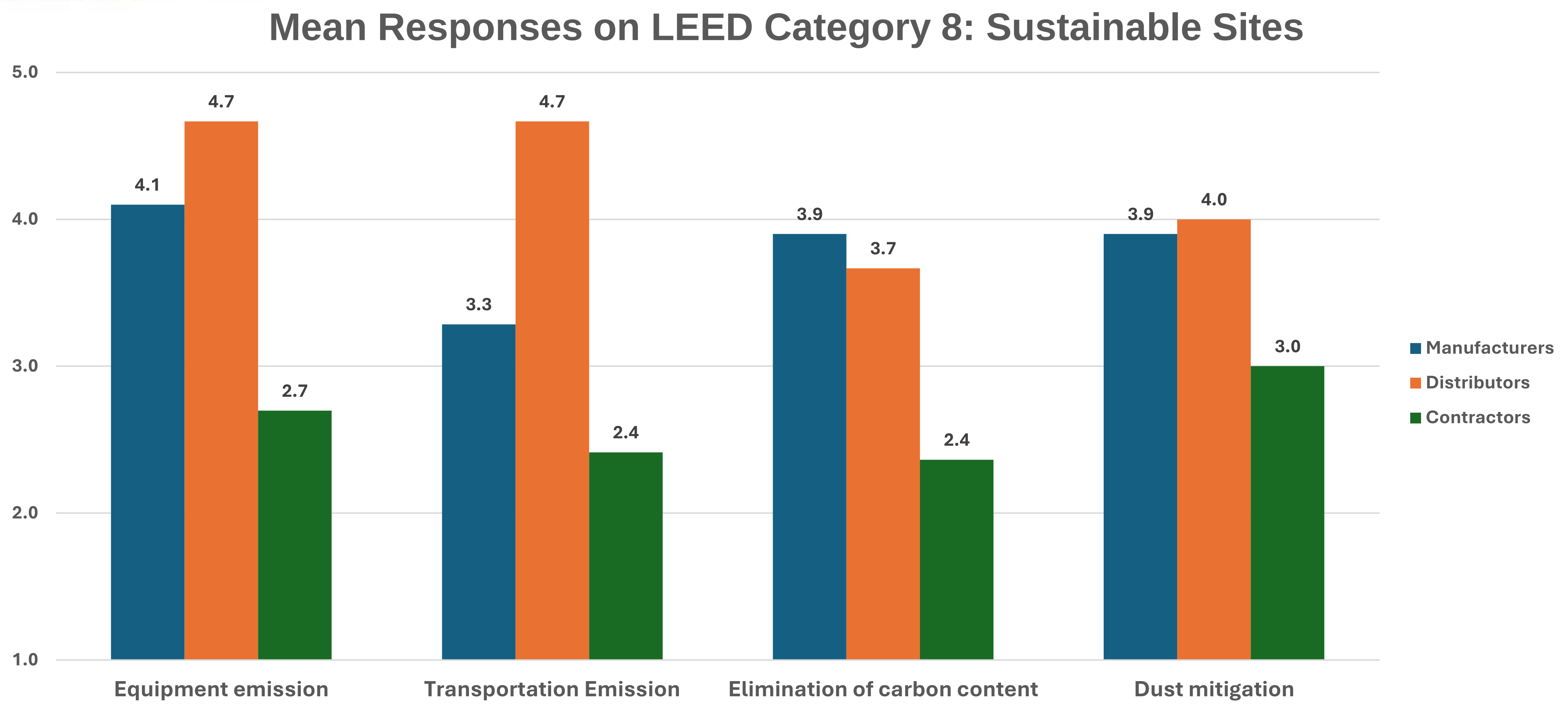
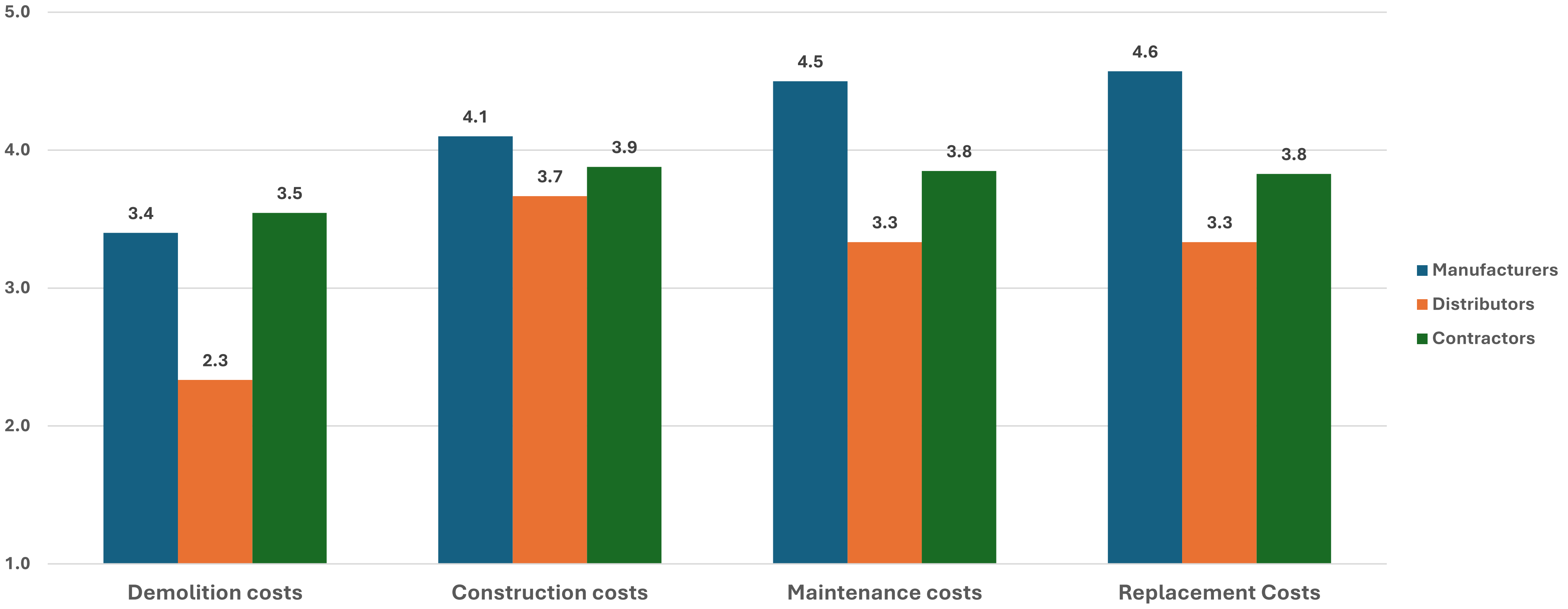

Mean Responses on LEED Category 7:
Water Efficiency
5
4
3
2
1
4
3.3
2
Manufacturers
Distributors
Contractors
Reducing Water Usage


Mean Responses on LEED Category 8: Sustainable Sites
5.0
4.0
3.0
2.0
1.0
4.1
4.7
2.7
3.3
4.7
2.4
3.9
3.7
2.4
3.9
4.0
3.0
Equipment emission
Transportation Emission
Elimination of carbon content
Dust mitigation
Manufacturers
Distributors
Contractors

Mean Responses on LEED Category 9: Other



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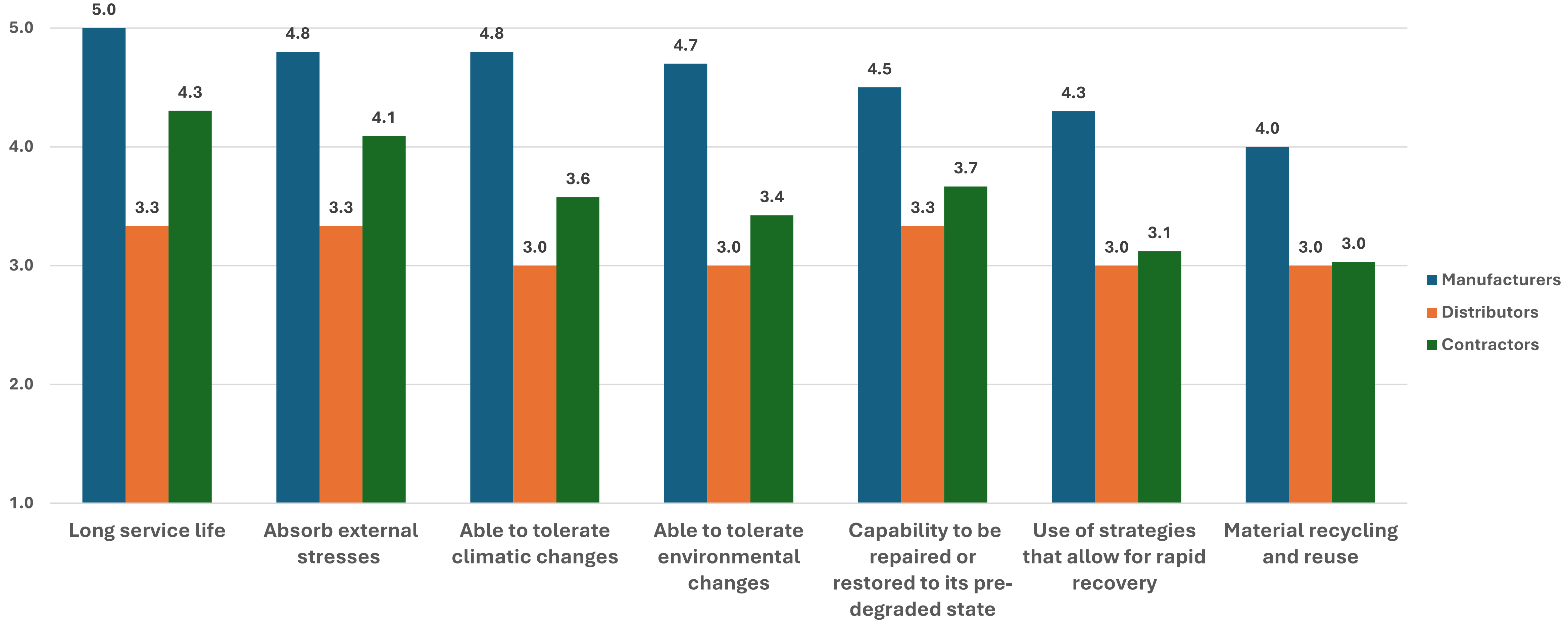
Resiliency Factor Comparison (M/D/C)

Mean Responses on structural and environmental resilience



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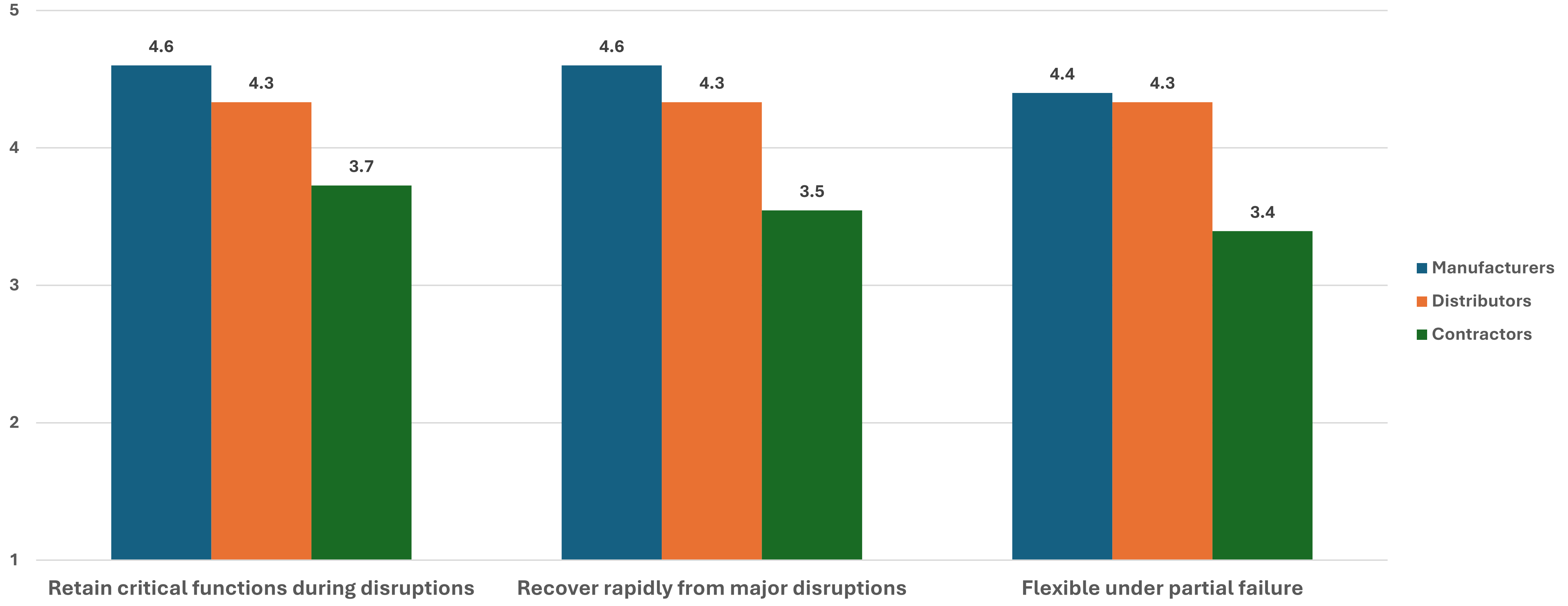
Mean Response on Functional & operational resilience



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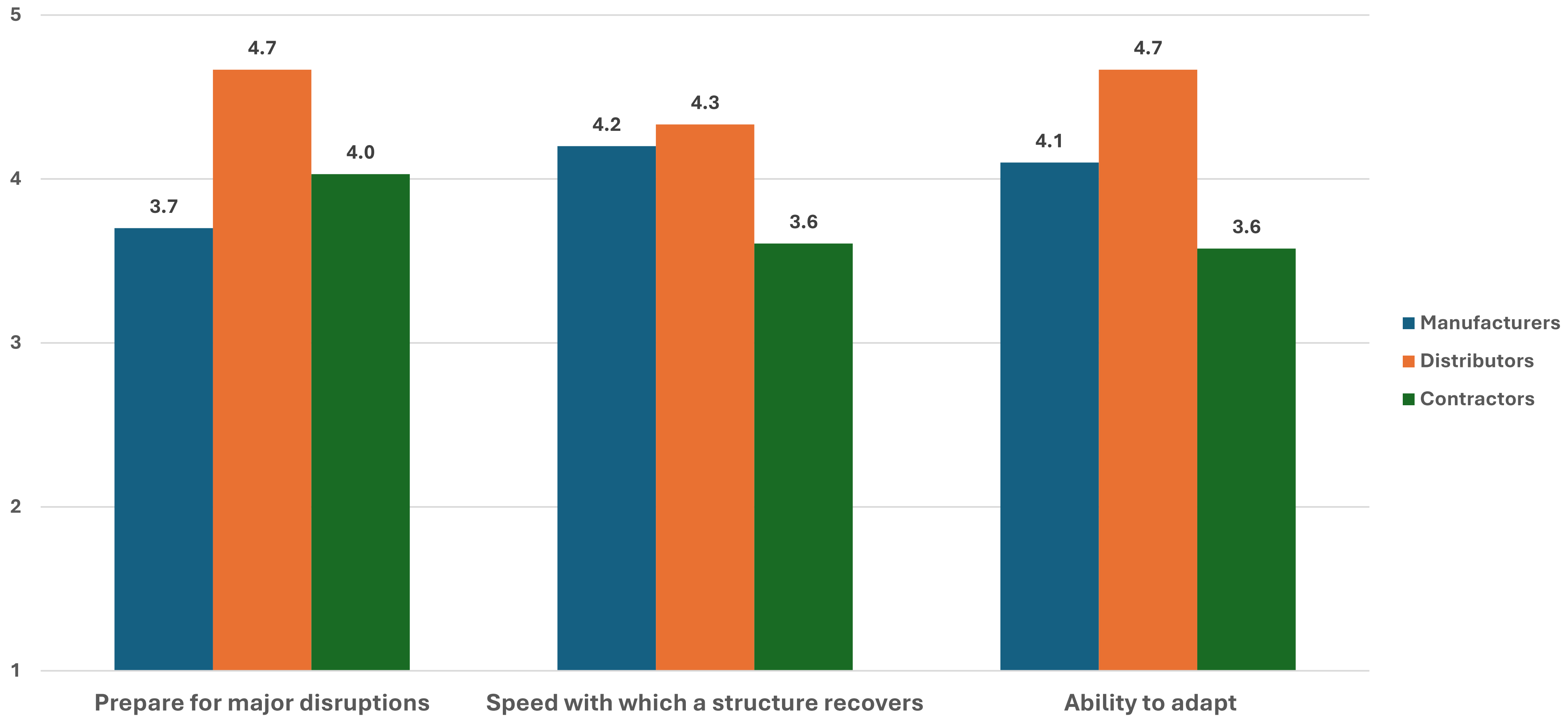
Mean Responses on Preparedness & response resilience



Interviews

Interview participants

Total Participants: 17

Manufacturers : 8

Distributors : 1

Contractors : 8

Manufacturers

#	Years in roofing industry	Experience in Sus. and Res.	Role
1	40	Yes	President
2	27	Yes	Director
3	35	Yes	Compliance
4	41	Yes	VP
5	29	Yes	Director
6	27	Yes	Director
7	15	No	Technical director
8	5	Yes	VP

Distributors

#	Years in roofing industry	Experience in Sus. and Res.	Role
1	5	Yes	Corporate social responsibility

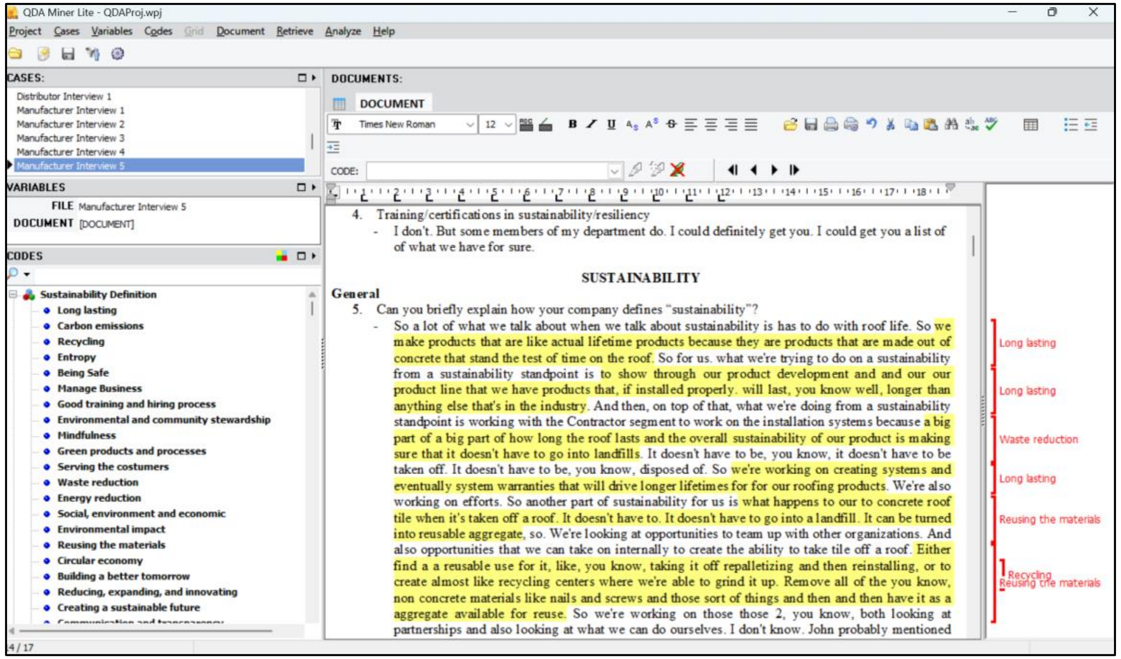
Contractors

#	Years in roofing industry	Experience in Sus. and Res.	Role
1	52	Yes	Founder
2	28	Yes	CEO
3	24	No	Owner
4	23	No	Owner
5	40	No	Founder
6	22	Yes	Owner
7	7	Yes	Technical services
8	24	Yes	Owner

Qualitative analysis

Raw transcripts → Preprocessing → Coding → Thematic analysis → Definitions extraction

Coding



Sustainability Factors

Resiliency Factors

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Sustainability factors

Sus. Factors	Definition	Total
Recycling	Repurposing or reusing waste materials from manufacturing or end-of-life roof systems, thus turning them into usable products and diverting them from the landfill.	14
Long lasting	Long-term performance of roofing products that focuses on durability, resiliency and extended performance. This reduces the need for premature replacement and extends the lifecycle of the product. This links to other concepts of sustainability by reducing waste, conserving resources, and protecting infrastructure over time.	12
Proximity	Reducing the transportation costs and minimizing environmental impact by locating manufacturing facilities near raw material sources, sourcing materials locally and having distribution centers and suppliers close to job sites.	10
Renewable energy	Energy derived from sources that are not depleted when used, such as solar power, which includes photovoltaic solar panels and battery-powered such as solar power, which includes photovoltaic solar panels and battery-powered equipment.	8
Waste recovery	Process of collecting, reintroducing and repurposing the waste materials to minimize landfill disposal and reduce the need for new raw materials. This may include capturing and reintegrating manufacturing by products, utilizing conveyor- based waste collection systems and partnering with third-party recyclers to maximize material reuse.	8

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Resiliency factors

Res. Factors	Definition	Total
Longevity	Long-term performance of the roof or the roofing products that can withstand adverse environmental conditions.	10
Inspections	Multiple levels of quality checks throughout the roofing installation process are conducted to ensure compliance with manufacturer standards and industry codes.	10
Ability to withstand environmental condition	A roof system's resilience against various environmental stressors, including extreme weather events like hurricanes, tornadoes, hail, excessive rain, snow loads, and temperature fluctuations. It involves durability against UV degradation, wind, and general wear and tear while maintaining its intended performance, such as waterproofing. A resilient roof not only endures normal aging but also sustains functionality through both foreseeable and unforeseen environmental challenges.	9
Recovery	Ability to bounce back from stress, whether physical, structural, or environmental.	6
Preparedness	It is a key focus ensuring readiness to respond to severe weather events like hurricanes, heavy rain and snow. It includes maintaining stockpile of materials and securing materials with ties and seals.	6

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Comparing sustainability and resiliency factors

Sustainability

Proximity
Renewable energy
Waste recovery
Maintainability
Reuse
Social stewardship
Waste reduction
Material sorting
Preventive maintenance
Incorporate recycled content
Environmental stewardship
Reduced emissions
Process Improvement

Resiliency

Inspections
Ability to withstand environ-mental condition
Recovery
Preparedness
Design to accepted standards
Installation methods
Continuity plans
Operations
Post-disaster mobilization
Increased durability
Stocking extra materials
Software and tools
Lifecycle cost
Repairability

Long lasting
Recycling
Energy Efficiency
Repairability
Quality/ Consistency
Warranties

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Comparing interview with survey - Sustainability factors

Top factors from survey

- Heating and cooling load requirements
- Thermal insulation
- Proximity
- Low maintenance
- Lifecycle of materials
- Equipment emission
- Recycling waste products
- Resistance to external forces
- Energy conservation techniques
- Reducing the use of non-renewable resources

Top factors from interview

- Recycling
- Long lasting
- Proximity
- Renewable energy
- Waste recovery
- Maintainability
- Reuse
- Social stewardship
- Waste reduction
- Energy efficiency

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Comparing interview with survey - Resiliency factors

Top factors from survey

- Long service life
- Recover rapidly
- Preparation for major disruptions
- Ability to adapt
- Retain critical functions
- Speed with which structure recovers
- Ability to absorb external stresses
- Ability to tolerate climate changes
- Capability to be repaired or restored
- Material recycling and reuse

Top factors from interview

- Longevity
- Inspections
- Ability to withstand environmental condition
- Recovery
- Quality and consistency
- Preparedness
- Design to accepted standards
- Warranties
- Installation methods
- Continuity plans

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Next Steps

Literature Review → Survey Design → Pilot Study → Data Analysis → Survey Questionnaire Refinement

→ Survey Distribution → Survey Data Collection → Data Preprocessing → Descriptive and Statistical Data analysis → Survey Results

→ Interviews with M/D/Cs → Interview analysis → Interview Findings → Final report → Curriculum

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Thank you!