GENERATIVE DESIGN ASSESSMENT

Autodesk Fusion 360 Generative Design Workflow

A market report from intrinSIM LLC

Contents

This market research paper provides an assessment of the Generative Design workflow in the January 2020 version of Autodesk Fusion 360. This assessment is based on the capability assessment model related to the Key Capability Areas of Generative Design for General Applicability and their associated criteria outlined in the intrinSIM Market Report entitled "A Vision for Generative Design" which explores the potential paradigm shift enabled by Generative Design and what is required to enable that design paradigm shift. intrinSIM has developed a process with quantified assessment for each key capability area in the capability assessment model and criteria outlined in "A Vision for Generative Design." This paper looks at the assessment of the Autodesk Fusion 360 Generative Design (Fusion 360 GD) workflow with respect to the Key Capability Areas of Generative Design for General Applicability. The same capability assessment model can be used for determining requirements for specific Generative Design applications, and the suitability of Generative Design workflows for specific applications.

intrinSIM has a collaborative working relationship with the ASSESS Initiative and shared research on this topic with the ASSESS Initiative. The ASSESS Initiative has published a Strategic Insight Paper entitled "*Understanding a Generative Design Enabled Design Process Paradigm Shift*." The ASSESS Initiative paper was written by Joe Walsh and Keith Meintjes and reviewed by consultants, academic researchers, and software vendors.

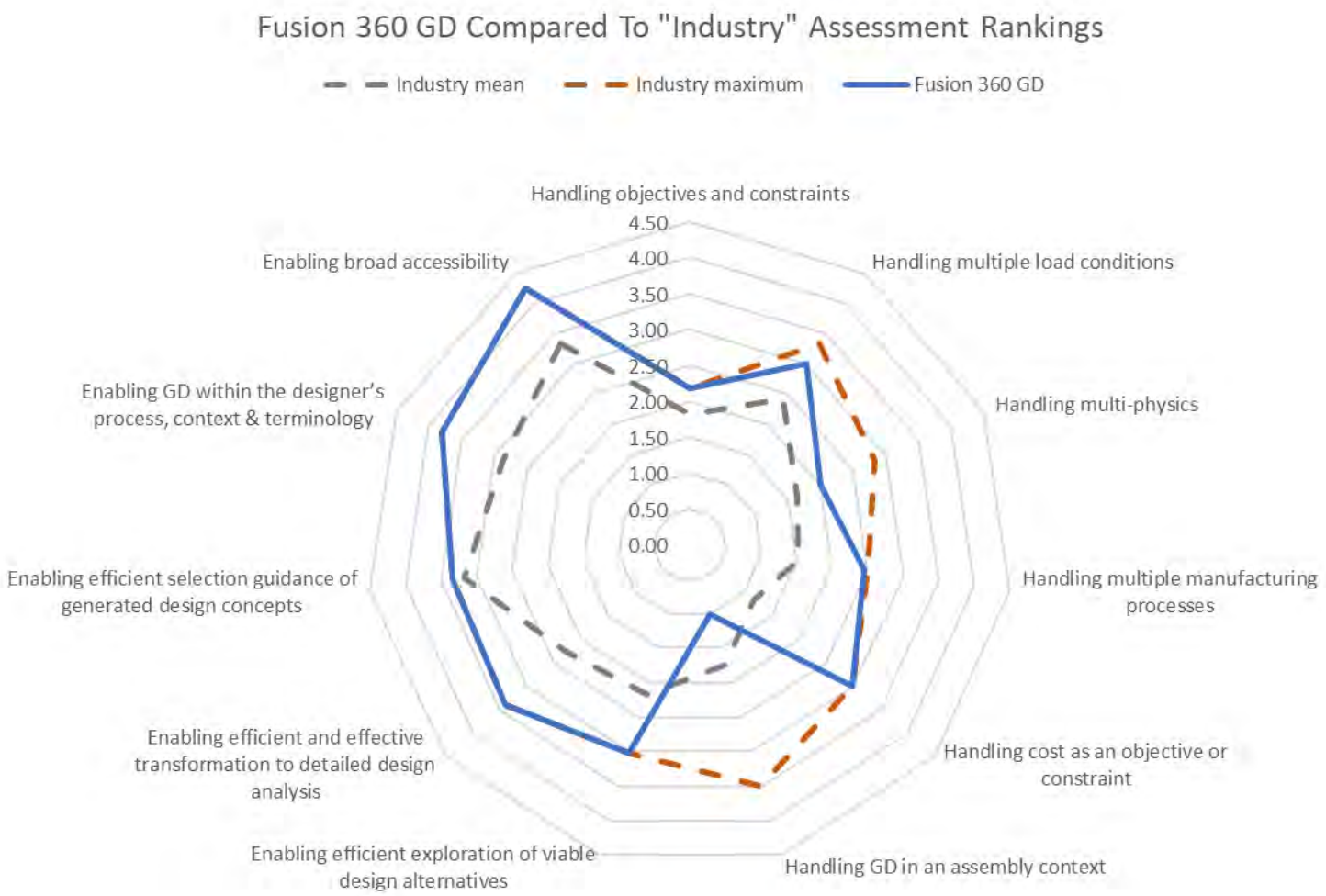
Autodesk Fusion 360 Generative Design Workflow Assessment Overview

Autodesk Fusion 360 provides Generative Design capabilities that are usable and accessible to a broad range of users, from students to simulation experts. The user experience is focused on enabling design engineers and designers to develop innovative concepts early in the design process without the need for simulation experts. Fusion 360 GD supports manufacturing constraints for a wide range of manufacturing processes. A single Generative Design study can evaluate multiple load cases, multiple manufacturing processes, and multiple materials. Fusion 360 GD also provides integrated manufacturing cost estimations across the different design options based on aPriori costing solutions, which results in a capability that is currently unique to filter design options by manufacturing cost estimates.

intrinSIM reviewed the January 2020 Fusion 360 GD workflow capabilities in collaboration with Autodesk and did a preliminary review of ten other Generative Design workflows capabilities based on publicly available information. The following capability summary classifications related to the industry were also determined for the Fusion 360 GD in each of the Key Capability Areas of Generative Design for General Applicability.

- "**market leader**" when the workflow ranking is at or very near the maximum rankings across the industry for the capability area.
  - **Fusion 360 GD** was classified as a **"market leader" in 8 Key Capability Areas.**
- **"strongly competitive"** when the workflow ranking is below the maximum rankings but above the mean rankings across the industry for the capability area.
  - **Fusion 360 GD** was classified as **"Strongly Competitive" in 2 Key Capability Area.**
- **"competitive"** when the workflow ranking is at or near the mean industry rankings for the capability area.
  - **Fusion 360 GD** was classified as "Competitive" in 0 Key Capability Areas.
- **"not competitive"** when the workflow ranking is below the mean rankings across the industry for the capability area.
  - **Fusion 360 GD** was classified as **"Not Competitive" in 1 Key Capability Area.**

The detailed assessment of the Fusion 360 GD workflow was combined with the preliminary reviews of ten other Generative Design workflows to develop an overall "industry" Generative Design assessment. The industry rankings include the mean and maximum rankings for all 11 Key Capability Areas of Generative Design for General Applicability for all 11 workflows (including Fusion 360 GD) reviewed.



Key Capability Areas of Generative Design for General Applicability

The ASSESS Initiative Strategic Insight Paper entitled "*Understanding a Generative Design Enabled Design Process Paradigm Shift*" outlined fifteen (15) Key Capability Areas related to Generative Design. The ASSESS Key Capability Areas are labeled based on two main concepts.

1. The first concept is related to "handling" specific capabilities related to the use case scenario definition.
2. The second concept is related to "enabling" user-related activities and workflows.

The intrinSIM Market Report entitled "A Vision for Generative Design" further defines eleven (11) of the ASSESS Initiative Key Capability Areas as the Key Capability Areas of Generative Design for General Applicability. These eleven (11) Key Capability Areas are focused on meeting the applicability requirements for the general deployment of Generative Design.

1. Handling all appropriate objectives and constraints
2. Handling multiple operational (load) conditions
3. Handling multi-physics
4. Handling multiple manufacturing processes
5. Handling cost as an objective or constraint
6. Handling Generative Design in an assembly/system context
7. Enabling informed, comprehensive and efficient exploration of viable design alternatives
8. Enabling efficient & effective transformation to detailed design analysis
9. Enabling efficient selection guidance of generated design concepts
10. Enabling Generative Design within the designer's process, context & terminology
11. Enabling broad accessibility to Generative Design

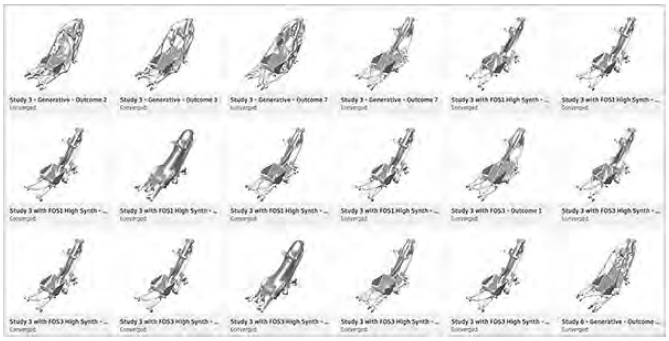
The remaining four Key Capability Areas from the ASSESS Initiative Strategic Insight paper entitled "Understanding a Generative Design Enabled Design Process Paradigm Shift" are considered the domain of specialist and specialty applications at this time in the intrinSIM Market Report entitled "A Vision for Generative Design."

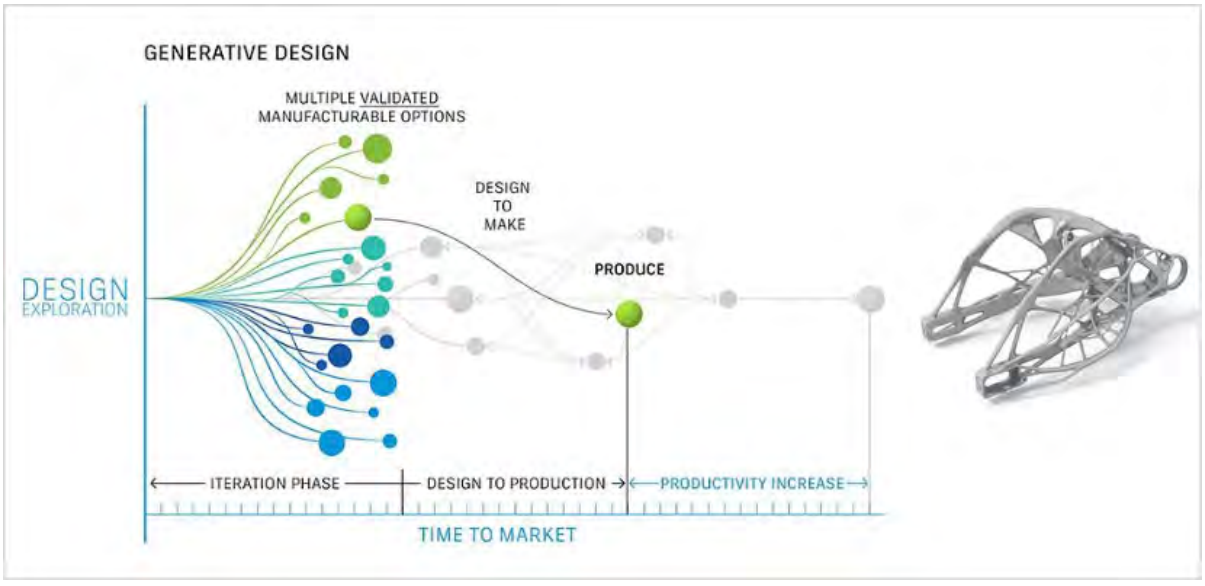
1. Handling complex materials
2. Handling transitions from solid to lattice structures
3. Handling uncertainties
4. Handling manufacturing process dependent materials

Fusion 360 GD Workflow Overview

Fusion 360 from Autodesk offers integrated simulation capabilities, topology optimization, CAD/CAM, and Generative Design all in one solution. Fusion 360 GD workflow supports manufacturing constraints for a wide range of manufacturing processes. A single Generative Design study can evaluate multiple load cases, multiple manufacturing processes, and multiple materials. Fusion 360 GD also provides integrated manufacturing cost estimations across the different design options based on aPriori costing solutions, which results in a currently unique capability to filter design options by manufacturing cost estimates. Fusion 360 GD provides Generative Design capabilities that are usable and accessible to a broad range of users, from students to simulation experts. The user experience is focused on enabling design engineers and designers to develop innovative concepts early in the design process without the need for simulation experts.

- Minimizes mass and material use while maintaining performance requirements and design &manufacturing constraints.
- Improves product performance.
- Enables understanding of the impact of design options on manufacturing cost.
- Enables cost reduction through part consolidation, material reduction, and manufacturing process selection.
- Provides simulation information transfer to Autodesk Fusion 360 Simulation and ANSYS Mechanical
- Enables review of trade-offs in materials, performance, manufacturing methods, and cost.
- Produces CAD-ready editable geometry to immediately edit in Fusion 360 or export to your CAD software of choice.
- Accelerates product development process by taking manufacturing into account early in the design development process





Fusion 360 GD Workflow Assessment by Key Capability Area

intrinSIM reviewed the Fusion 360 GD workflow capabilities in collaboration with Autodesk and did a preliminary review of ten other Generative Design workflows capabilities based on publicly available information.

Handling all appropriate objectives and constraints

Real-world design scenarios almost always have multiple design objectives and constraints, even within a single loading condition. For instance, a structural design problem may include objectives and constraints on stiffness, stress, fatigue life, and cost. Merely performing a topology optimization for a target stiffness does not address the full range of objectives and constraints that a designer is faced with.

To be broadly deployable for general applicability, Generative Design workflows need to support a broad range of design objectives and constraints that match the design criteria being used without Generative Design. Designs generated for an incomplete set of objectives and constraints have limited usage as design inspiration and cannot be used directly as the start of the design process. Different combinations of design objectives and constraints for the same design space and use cases should result in different design options.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Handling all appropriate objectives and constraints."

The capability ranking for Fusion 360 GD workflow for "Handling all appropriate objectives and constraints" is the same as the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** for capabilities related to "Handling all appropriate objectives and constraints."

Handling all appropriate objectives and constraints		
	Other	Industry
minimum	1.49	1.49
mean	1.79	1.82
maximum	2.16	2.18
Fusion 360 GD	**2.18**	**2.18**

Handling multiple operational (load) conditions

Real-world design scenarios rarely involve a single use case or operational (loading) condition and indeed usually must deal with multiple operational conditions (load cases). For instance, building and bridge designs have multiple conditions for dead loads, live loads, wind loads, seismic loads, and various combinations of these loads. Mechanical components need to address start-up conditions, multiple operating conditions and shut down.

To be broadly deployable for general applicability, Generative Design workflows need to support multiple load (operational) conditions (use cases) that match to the full range of use cases being used in the traditional design process without Generative Design. Generative Design needs to intelligently work with design scenarios that include multiple load conditions to have a significant impact on the design process. These multiple load conditions are not encountered simultaneously but represent different operational conditions. Different load cases will result in different material distribution, and just combining all material from all load cases is fundamentally sub-optimal, resulting in dramatic overdesign.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Handling multiple operational (load) conditions."

The capability ranking for Fusion 360 GD workflow for "Handling all appropriate objectives and constraints" is between the mean and the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as **strongly competitive** related to "Handling multiple operational (load) conditions."

Handling multiple operational (load) conditions		
	Other	Industry
minimum	1.00	1.00
mean	2.35	2.41
maximum	3.33	3.33
Fusion 360 GD	**3.00**	**3.00**

Handling multi-physics

Real-world design scenarios often also involve multiple physics (structural, vibration, fluids, electromagnetics, …) phenomena either in a single load condition or as different load conditions. Generative Design needs to deal appropriately with the physics of interest for the design scenario under investigation.

To be broadly deployable for general applicability, Generative Design workflows need to support a reasonable set of combinations of different physics with their unique design objectives and constraints such as structural, thermal, and vibration that match the use cases being used without Generative Design. These multiple physics can usually be unlinked or loosely coupled but need to be accounted for simultaneously in the design generation.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Handling multi-physics."

The capability ranking for Fusion 360 GD workflow for "Handling multi-physics" is equal to the minimum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as **strongly competitive** related to "Handling multi-physics."

Handling multi-physics		
	Other	Industry
minimum	1.00	1.00
mean	1.61	1.64
maximum	2.83	2.83
Fusion 360 GD	**2.00**	**2.00**

Handling multiple manufacturing processes

Real-world design choices must cover multiple manufacturing options. Generative Design needs to address the design constraints of a wide range of manufacturing processes, including both additive and subtractive processes that result in viable design alternatives for each manufacturing process.

To be broadly deployable for general applicability, Generative Design workflows need to support a broad range of manufacturing processes that match the manufacturing processes being used without Generative Design. Additive Manufacturing will drive Generative Design applications in the short term; however, other manufacturing processes also need to be supported to allow for larger volumes of production and existing manufacturing capabilities.

Generative Design enables different designs for different manufacturing plants and processes that offer similar performance and reliability. A small run production may be better for Additive Manufacturing, while Subtractive Manufacturing will be more cost-effective for large run production. This concept introduces a paradigm shift in perspective that the design is not about a specific geometry but a family of geometries to provide the desired functions, performance, and reliability. As production ramps up, the "best" manufacturing process could change, and the resulting geometry could change significantly while retaining the function and performance within an acceptable variability. In other words, a replacement part may not resemble the shape of the part it is replacing, but it will provide the same function and performance.

Generative Design tools need to enable a means to capture enterprise-wide manufacturing process constraints as well as provide a reasonable set of default manufacturing processes and constraints.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Handling multiple manufacturing processes."

The capability ranking for Fusion 360 GD workflow for "Handling multiple manufacturing processes" is nearly equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Handling multiple manufacturing processes."

Handling multiple manufacturing processes		
	Other	Industry
minimum	0.58	0.58
mean	1.43	1.52
maximum	2.50	2.50
Fusion 360 GD	**2.45**	**2.45**

Handling cost as an objective or constraint

Real-world design scenarios should include the cost of production as either a design objective (minimization) or as a constraint. Omitting cost as a consideration results in design options that are not feasible to manufacture. Generative Design tools rarely account for manufacturing cost today. Cost should be available to be defined either as an optimization objective or a constraint at the user's discretion. The incorporation of cost models and resulting cost estimates is key to the Generative Design process and should significantly reduce the number of design options to consider.

To be broadly deployable for general applicability, Generative Design workflows need to support cost estimations since the cost is always a factor in design criteria currently being performed without Generative Design. Without the ability to account for production costs, the danger is that designs can be generated that are not economically feasible, with the user having little to no capability to assess their costs and economic feasibility. The ability to account for cost as a filter on designs generated is a critical minimum requirement to enable broader use of Generative Designs. The other interesting side effect will be that the selection of "best" manufacturing processes could be determined based on the available manufacturing processes, the cost objectives/constraints, and the desired run rate.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Handling cost as an objective or constraint."

The capability ranking for Fusion 360 GD workflow for "Handling cost as an objective or constraint" is equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Handling cost as an objective or constraint."

Handling cost as an objective or constraint		
	Other	Industry
minimum	1.00	1.00
mean	1.00	1.18
maximum	1.00	3.00
Fusion 360 GD	**3.00**	**3.00**

At the time of this review, no other generative design workflows offered any means to incorporate cost simulation as part of the Generative Design workflow. Estimating manufacturing costs for multiple manufacturing processes and providing the ability to filter and sort based on manufacturing cost is unique to the Fusion 360 GD workflow at the time this report was authored.

Handling Generative Design in an assembly/system context

To be broadly deployable for general applicability, Generative Design workflows need to support working in assembly context to enable a more accurate definition of loads and to generate designs for multiple components in an assembly to maximize the efficiency of the assembly when not all parts in the assembly can be consolidated into one.

Generative Design tools typically work on a component by component basis. This approach has three inherent issues, as follows:

1. The load distribution in an assembly context is usually a function of the properties (e.g., stiffness) of the component, and changing properties of a component results in a different load path.
2. It may be difficult to define realistic loads and boundary conditions that the component sees as these are a function of the full assembly context (especially for someone who is not a simulation expert).
3. The loading complexity issue is exacerbated if the goal is to apply Generative Design to multiple (or all) of the components in an assembly.
    a. Performing part by part Generative Design assumes properties of the other components that may change.

The goal is for Generative Design should be to support the simultaneous design of multiple components in an assembly context driven by the assembly objectives and constraints that account for the changing load distributions. The desired result is not a set of component designs but a set of assembly designs with different component geometries that, when combined, meet the performance objectives and constraints of the assembly.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Handling Generative Design in an assembly/system context."

The capability ranking for Fusion 360 GD workflow for "Handling Generative Design in an assembly/system context" is equal to the minimum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as **not competitive** related to "Handling Generative Design in an assembly/system context."

Handling Generative Design in an assembly/system context		
	Other	Industry
minimum	1.00	1.00
mean	1.82	1.74
maximum	3.50	3.50
Fusion 360 GD	**1.00**	**1.00**

Enabling informed, comprehensive and efficient exploration of viable design alternatives

Generative Design should enable the ability to explore a broader range of design options than the human designer. A comprehensive exploration of design concepts that would otherwise not be considered. This broader range of design alternatives should include variations on material properties, manufacturing processes, as well as various lattice structures types or solid material. The efficient exploration should enable exploration of all the viable designs that meet the specified constraints with single and multiple design objectives. Exploration of all viable designs is best done with a single Generative Design scenario but can be accomplished with multiple Generative Design scenarios. For multi-objective optimization, the ability to understand trade-offs between objectives is critical.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Enabling informed, comprehensive and efficient exploration of viable design alternatives."

Enabling efficient exploration of viable design alternatives		
	Other	Industry
minimum	1.42	1.42
mean	2.08	2.16
maximum	2.81	3.02
Fusion 360 GD	**3.02**	**3.02**

The capability ranking for Fusion 360 GD workflow for "Handling all appropriate objectives and constraints" is equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Enabling informed, comprehensive, and efficient exploration of viable design alternatives."

Enabling efficient & effective transformation to detailed design analysis

Generative Design needs to enable a smooth transition to detailed design analysis using traditional simulation methodologies. This smooth transition requires the automated creation of detailed simulation models with a transformation of the problem definition, material distribution, and any uncertainties in the use case definition to these detailed simulation models. Manual creation of detailed simulation models is at best inefficient (requires a simulation expert) and at worst confusing as it may result in apples to oranges comparisons casting doubt on the validity of the Generative Design process. Generative Design should support the automated creation of detailed simulation models as part of the Generative Design process to enable refinement of viable designs.

Generative Design does not replace or remove the need for more detailed validation of the design. Generative Design intends to provide feasible design concepts that are significantly more likely to pass more detailed performance validations. Generative Design should result in a significant reduction in the design/validate iteration cycles and thereby significantly reduce the amount of design validation analysis that needs to be run.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Enabling efficient & effective transformation to detailed design analysis."

The capability ranking for Fusion 360 GD workflow for "Enabling efficient & effective transformation to detailed design analysis" is equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Enabling efficient & effective transformation to detailed design analysis."

Enabling efficient & effective transformation to detailed design analysis		
	Other	Industry
minimum	1.00	1.00
mean	2.16	2.27
maximum	3.20	3.41
Fusion 360 GD	**3.41**	**3.41**

Enabling efficient selection guidance of generated design concepts

One of the benefits and disadvantages of Generative Design is the ability to enable a comprehensive exploration of the design space, which may result in a large number of viable design options. However, no user of Generative Design has the inclination, time, or ability to review thousands of design options or even hundreds. Most designers and engineers are interested in a "Top Ten" list or less.

To be broadly deployable for general applicability, Generative Design workflows need to enable efficient refinement to the viable designs of interest. Without this efficient selection of meaningful design options, the design engineer's time is not saved but merely moved to the task of reviewing design alternatives.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Enabling efficient selection guidance of generated design concepts."

The capability ranking for Fusion 360 GD workflow for "Enabling efficient selection guidance of generated design concepts" is equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Enabling efficient selection guidance of generated design concepts."

Enabling efficient selection guidance of generated design concepts		
	Other	Industry
minimum	2.92	2.92
mean	3.16	3.17
maximum	3.33	3.33
Fusion 360 GD	**3.33**	**3.33**

However, there is only a small difference between the minimum value (2.92), the mean value (3.17), and the maximum value (3.33) for this capability area, which indicates that the capabilities across multiple Generative Design workflows in this capability area are similar. All workflows evaluated are ranked highly in this Key Capability area.

Enabling Generative Design within the designer's process, context, & terminology

The earlier in the design process that this can be explored, the higher the potential benefit. The use of Generative Design early in the design process means that the target user is not the simulation expert but the engineers and designers responsible for early design concepts and the maturation of the design. For Generative Design to be effective, it must be well integrated into the designer's workflow, and the definition of the Generative Design problem must be in the context of their understanding and information available at that time as well as terminology that is consistent with their design requirements, methodologies, and objectives.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Enabling Generative Design within the designer's process, context & terminology."

The capability ranking for Fusion 360 GD workflow for "Enabling Generative Design within the designer's process, context & terminology" is equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Enabling Generative Design within the designer's process, context & terminology."

Enabling Generative Design within the designer's process, context, & terminology		
	Other	Industry
minimum	2.17	2.17
mean	2.76	2.85
maximum	3.25	3.79
Fusion 360 GD	**3.79**	**3.79**

Enabling broad accessibility to Generative Design

For Generative Design to enable a paradigm shift related to the design process, it must be readily available and usable by all of those who would be involved in the paradigm shift. Enabling broad accessibility to Generative Design is key to enabling the envisioned paradigm shift. Fusion 360 GD capabilities are usable and accessible to a broad range of users, from students to simulation experts. The user experience is focused on enabling design engineers and designers to develop innovative concepts early in the design process without the need for simulation experts. Autodesk has also elected to make Fusion 360 GD freely available to students to explore design innovation.

The table indicates the results for the Fusion 360 GD workflow capability rankings as compared to "Other" Generative Design workflows and the "industry" (including Fusion 360 GD) workflow capability rankings for "Enabling broad accessibility to Generative Design."

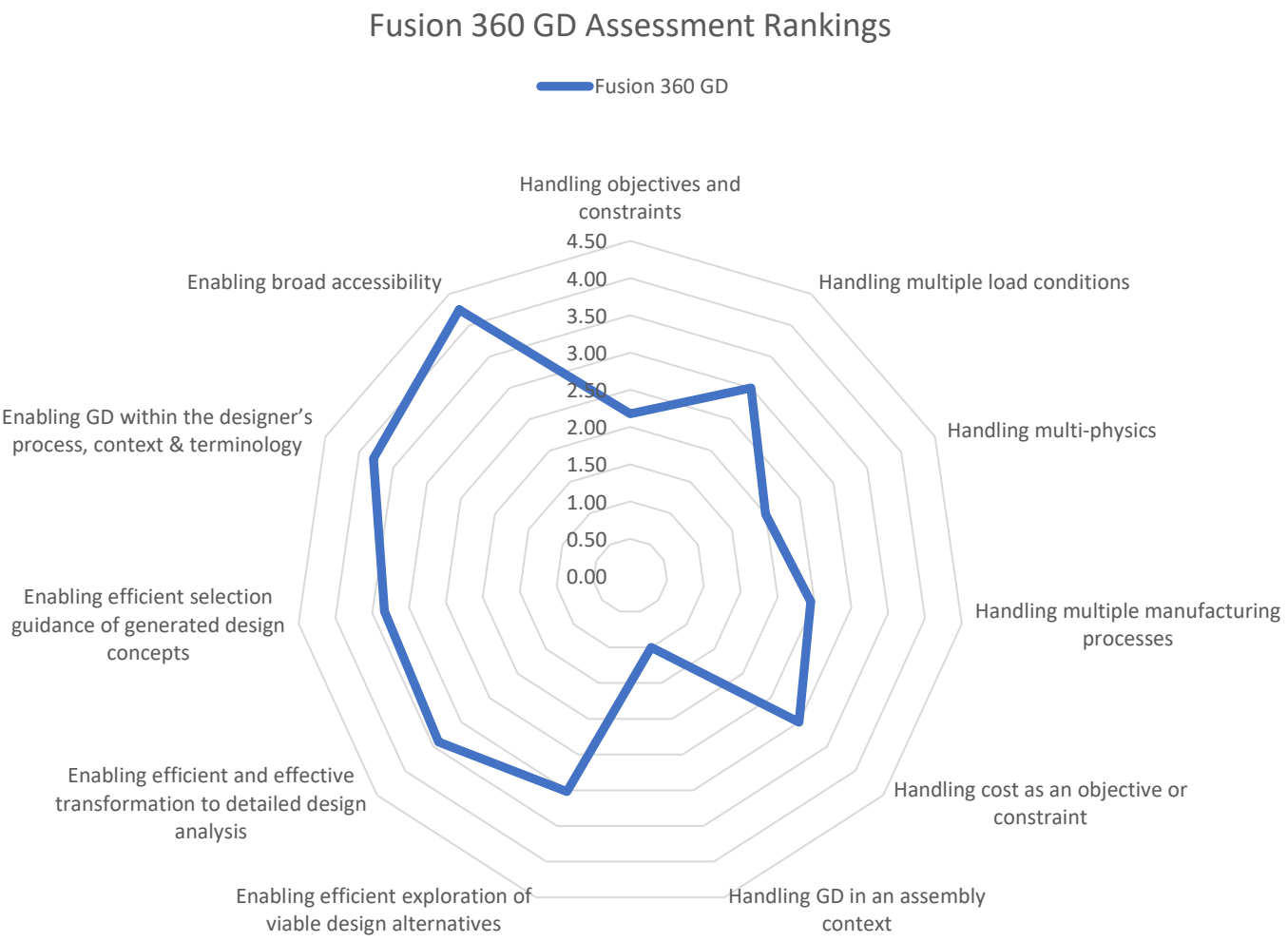
The capability ranking for Fusion 360 GD workflow for "Enabling broad accessibility to Generative Design" is equal to the maximum value for the industry. Fusion 360 GD workflow is classified by intrinSIM as a **market leader** related to "Enabling broad accessibility to Generative Design."

Enabling broad accessibility to Generative Design		
	Other	Industry
minimum	2.33	2.33
mean	3.25	3.34
maximum	3.75	4.25
Fusion 360 GD	**4.25**	**4.25**

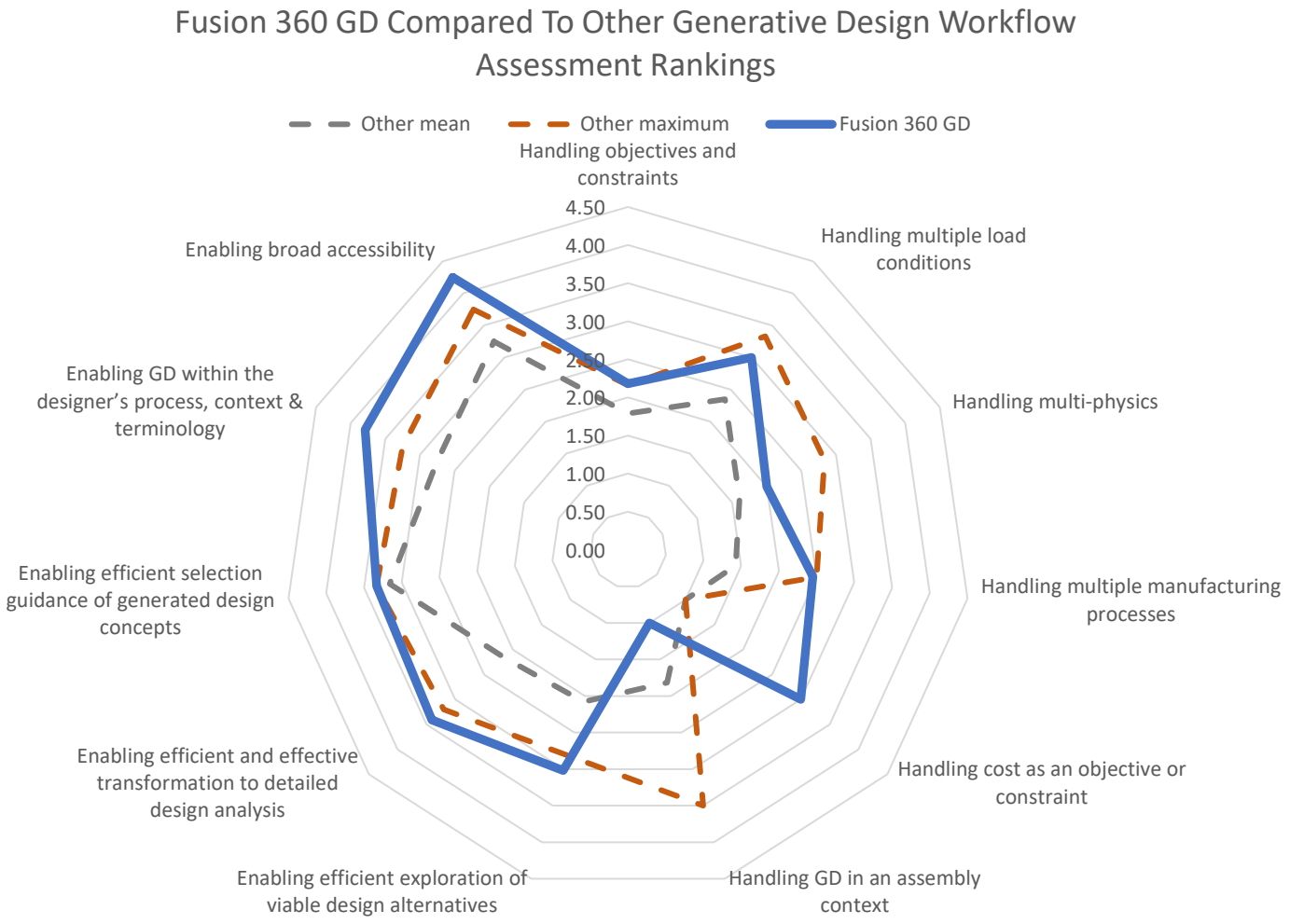
Fusion 360 GD Workflow Assessment Summary

Autodesk Fusion 360 provides Generative Design capabilities that are usable and accessible to a broad range of users, from students to simulation experts. The user experience is focused on enabling design engineers and designers to develop innovative concepts early in the design process without the need for simulation experts. Fusion 360 GD workflow supports manufacturing constraints for a wide range of manufacturing processes. A single Generative Design study can evaluate multiple load cases, multiple manufacturing processes, and multiple materials. Fusion 360 GD workflow also provides integrated manufacturing cost estimations across the different design options based on aPriori costing solutions, which results in a currently unique capability to filter design options by manufacturing cost estimates.

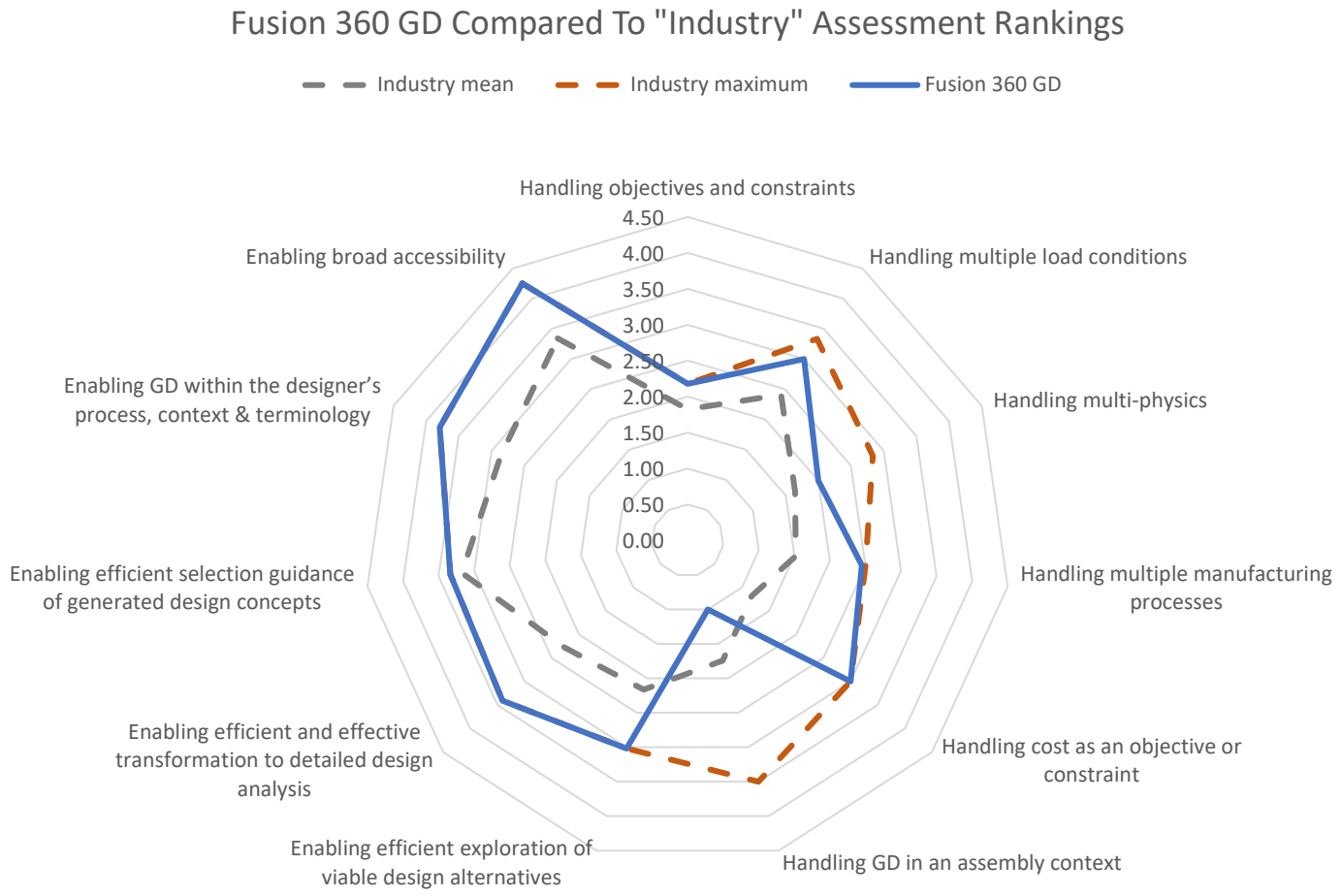
The following illustrates the intrinSIM rankings of the Fusion 360 GD workflow (January 2020 version) for the Key Capability Areas of Generative Design for General Applicability.



The following illustrates the intrinSIM rankings of the Fusion 360 GD workflow for the Key Capability Areas of Generative Design for General Applicability compared to the mean and maximum rankings for the "Other" ten Generative Design workflows preliminarily reviewed by intrinSIM.



The following illustrates the intrinSIM rankings of the Fusion 360 GD workflow for the Key Capability Areas of Generative Design for General Applicability compared to the mean and maximum rankings for the "industry" Generative Design solutions (which includes Fusion 360 GD and all other workflows reviewed at this time).



- Fusion 360 GD workflow was classified by intrinSIM as **a "market leader"** in 8 Key Capability Areas.
  - Handling all appropriate objectives and constraints
  - Handling multiple manufacturing processes
  - Handling cost as an objective or constraint (currently unique capabilities)
  - Enabling informed, comprehensive and efficient exploration of viable design alternatives
  - Enabling efficient & effective transformation to detailed design analysis
  - Enabling efficient selection guidance of generated design concepts
  - Enabling Generative Design within the designer's process, context & terminology
  - Enabling broad accessibility to Generative Design
- Fusion 360 GD workflow was classified by intrinSIM as **"Strongly Competitive"** in 2 Key Capability Areas.
  - Handling multiple operational (load) conditions
  - Handling multi-physics
- Fusion 360 GD workflow was classified by intrinSIM as **"Not Competitive"** in 1 Key Capability Area.
  - Handling Generative Design in an assembly context

Suitability Analysis of Fusion 360 GD Workflow

The intrinSIM assessment methodology can also be used to quantify the requirements of a potential Generative Design application. Determination of both the requirements of a potential application and the capabilities of a specific Generative Design workflow enables the determination of the "suitability" of the Generative Design workflow through the calculation of suitability indices for the potential application and the specific Generative Design workflow.

An approach for a suitability assessment is proposed in "A Vision for Generative Design" an intrinSIM Market Report that is based on a quantifiable "Suitability Index" calculated for each Generative Design capability area of interest by dividing the Generative Design workflow capability assessment value by the corresponding requirements value for the potential application in the same Key Capability Area. A Suitability Index of less than 1.0 indicates that the Generative Design workflow evaluated is not suitable to support the intended application.

This approach results in multiple suitability qualifications (one for each capability area). Determination of the minimum and mean Sustainability Indices make it possible to support further qualification of the suitability of the proposed Generative Design workflow for the potential application as follows:

- **Clearly suitable**
  - Minimum Suitability Index is equal to or greater than 1.0
- **Possibly suitable and needs further investigation**
  - Mean Suitability Index is equal to or greater than 1.0
  - Minimum Suitability Index is less than 1.0
- **Clearly not suitable**
  - Mean Suitability Index is less than 1.0

This approach will be used in this paper to determine the suitability of the Fusion 360 GD workflow for five (5) different sample applications.

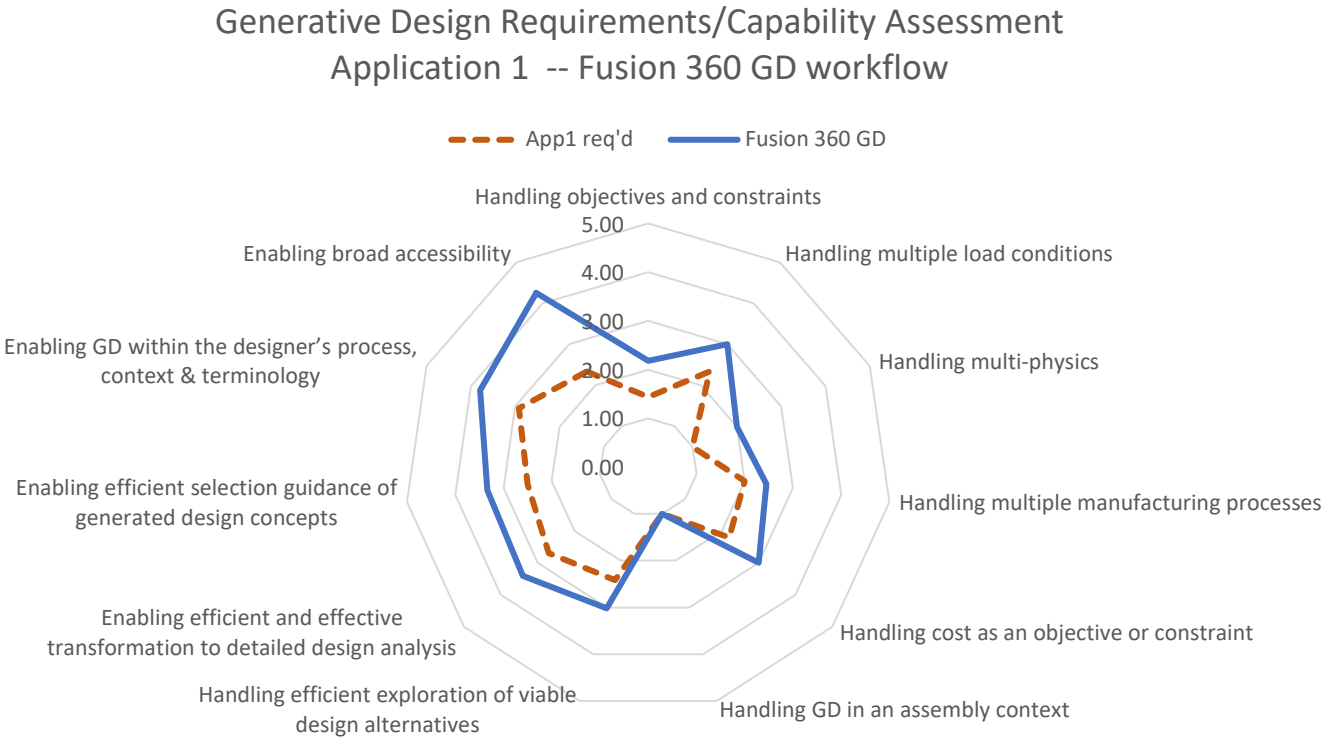
1. Conceptual component design for structures
   a. **Clearly Suitable**
2. Conceptual component design for linear static stress, temperature & vibration
   a. **Possibly suitable and needs further investigation**
3. Transmission case NVH optimization (case only)
   a. **Clearly Suitable**
4. Transmission case NVH optimization (assembly context)
   a. **Possibly suitable and needs further investigation**
5. Exploring Manufacturing Processes to minimize Manufacturing Costs for Medium-Large Production Runs
   a. **Clearly Suitable**

The ranking approach outlined by the ASSESS Initiative and used by intrinSIM does include evaluation of the range of physics and manufacturing processes supported. The ranking approach, however, does not include a detailed review of specific details related to capabilities for specific physics and specific manufacturing processes supported.

Determination of whether the specific physics and manufacturing processes are supported can and should also be done after the initial evaluation of suitability as outlined by the ASSESS Initiative.

Sample Application 1: Conceptual component design for structures

Application Description	**Conceptual component design for structures**
Goals/Objectives	minimize weight/mass
Design Constraints	Stress or Safety Factor Max Displacement Cost
Physics Required	Linear static stress analysis
Number Load Cases Required	Multiple load cases
Manufacturing Processes of interest	Additive Multiple subtractive processes Casting Forging 2 axis Cutting 3 Axis milling
Materials to investigate	Multiple metals Steel Aluminum Titanium Cast Iron
Cost information required	Cost estimate of all design options Filter by cost
Target User	Design Engineer

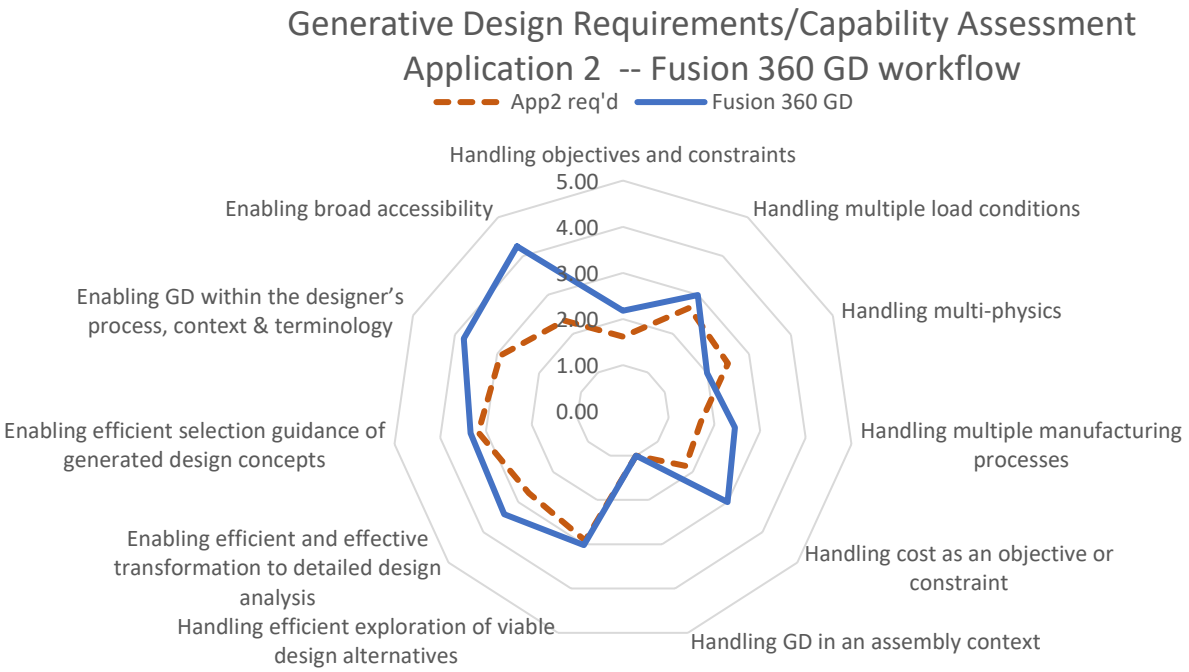


Suitability Indices for Sample Application 1	
Handling objectives and constraints	**1.52**
Handling multiple load conditions	**1.29**
Handling multi-physics	**2.00**
Handling multiple manufacturing processes	**1.23**
Handling cost as an objective or constraint	**1.36**
Handling GD in an assembly context	1.00
Handling efficient exploration of viable design alternatives	**1.25**
Enabling efficient and effective transformation to detailed design analysis	**1.26**
Enabling efficient selection guidance of generated design concepts	**1.33**
Enabling GD within the designer's process, context & terminology	**1.30**
Enabling broad accessibility	**1.82**
Minimum Suitability Index	**1.00**
Mean Suitability Index	**1.40**

Based on the Sample Application 1 requirements and the suitability analysis, the Autodesk Fusion 360 Generative Design workflow would be **"Clearly suitable"** for "Conceptual component design for structures."

Sample Application 2: Conceptual component design for linear stress, temperature & vibration

Application Description	**Conceptual component design for linear stress, temperature & vibration**
Goals/Objectives	minimize weight/mass
Design Constraints	Stress or Safety Factor Max Displacement Max Temperature Minimum Natural Frequency Cost
Physics Required	Linear static stress analysis Thermal Vibration
Number Load Cases Required	Multiple load cases
Manufacturing Processes of interest	Additive Multiple subtractive processes Casting Forging 2 axis Cutting 3 Axis milling
Materials to investigate	Steel Aluminum Titanium Cast Iron
Cost information required	Cost estimate of all design options Filter by cost
Target User	Design Engineer



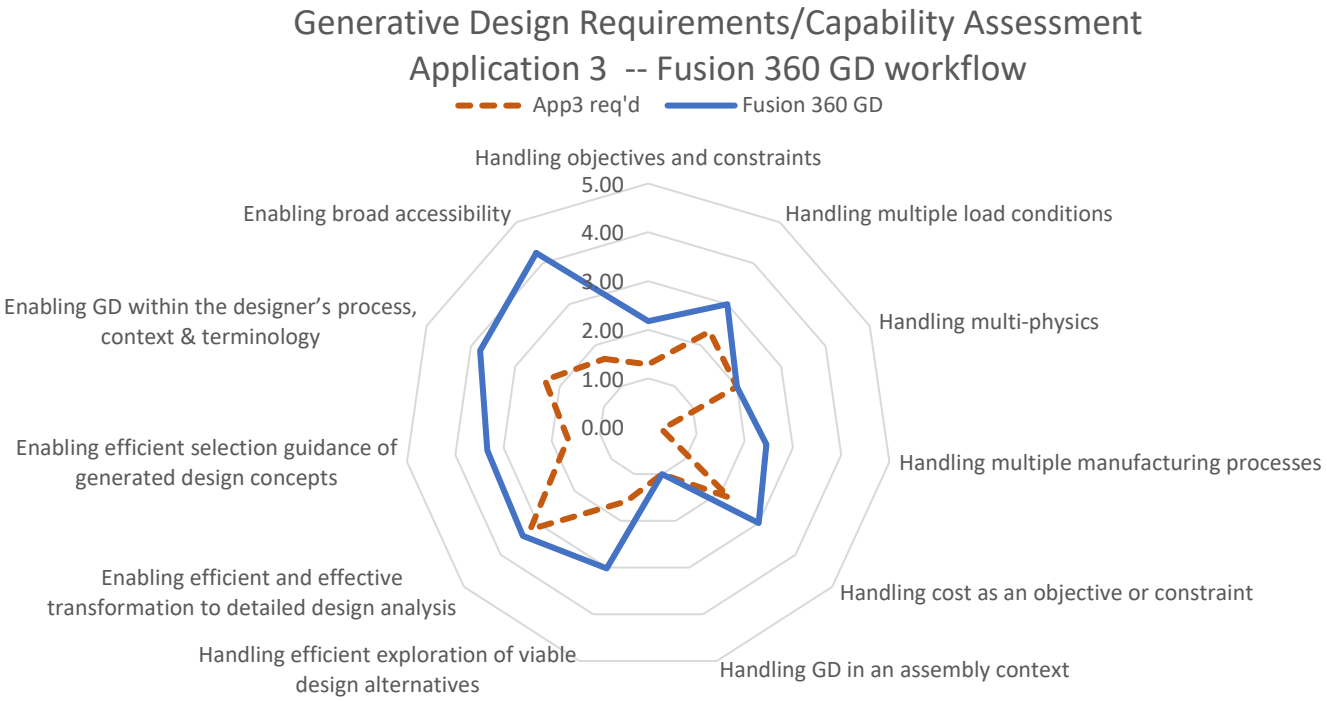
Suitability Indices for Sample Application 2	
Handling objectives and constraints	**1.35**
Handling multiple load conditions	**1.13**
Handling multi-physics	**0.80**
Handling multiple manufacturing processes	**1.44**
Handling cost as an objective or constraint	**1.67**
Handling GD in an assembly context	1.00
Handling efficient exploration of viable design alternatives	**1.04**
Enabling efficient and effective transformation to detailed design analysis	**1.26**
Enabling efficient selection guidance of generated design concepts	**1.05**
Enabling GD within the designer's process, context & terminology	**1.30**
Enabling broad accessibility	**1.82**
Minimum Suitability Index	**0.80**
Mean Suitability Index	**1.26**

Based on the Sample Application 2 requirements and the suitability analysis, the Autodesk Fusion 360 Generative Design workflow would be **"Possibly suitable and needs further investigation"** for "Conceptual component design for structures."

A quick review of the suitability indices would show that the potential issue is related to the physics coverage. The Fusion 360 GD workflow could be used to generate designs based on stress analysis and vibration; however, additional analysis and redesigns would be needed to account for thermal behavior as this physics is not supported by the Fusion 360 GD workflow.

Sample Application 3: Transmission case NVH optimization (case only)

Application Description	**Transmission case NVH optimization (case only)**
Goals/Objectives	minimize weight minimize radiated noise
Design Constraints	Maximum Stress below a specified level Natural frequency spectrum requirements
Physics Required	Noise & Vibration
Number Load Cases Required	Multiple load cases
Manufacturing Processes of interest	Casting
Materials to investigate	Steel Aluminum Cast Iron
Cost information required	Cost estimate of all design options Filter by cost
Target User	CAE analyst

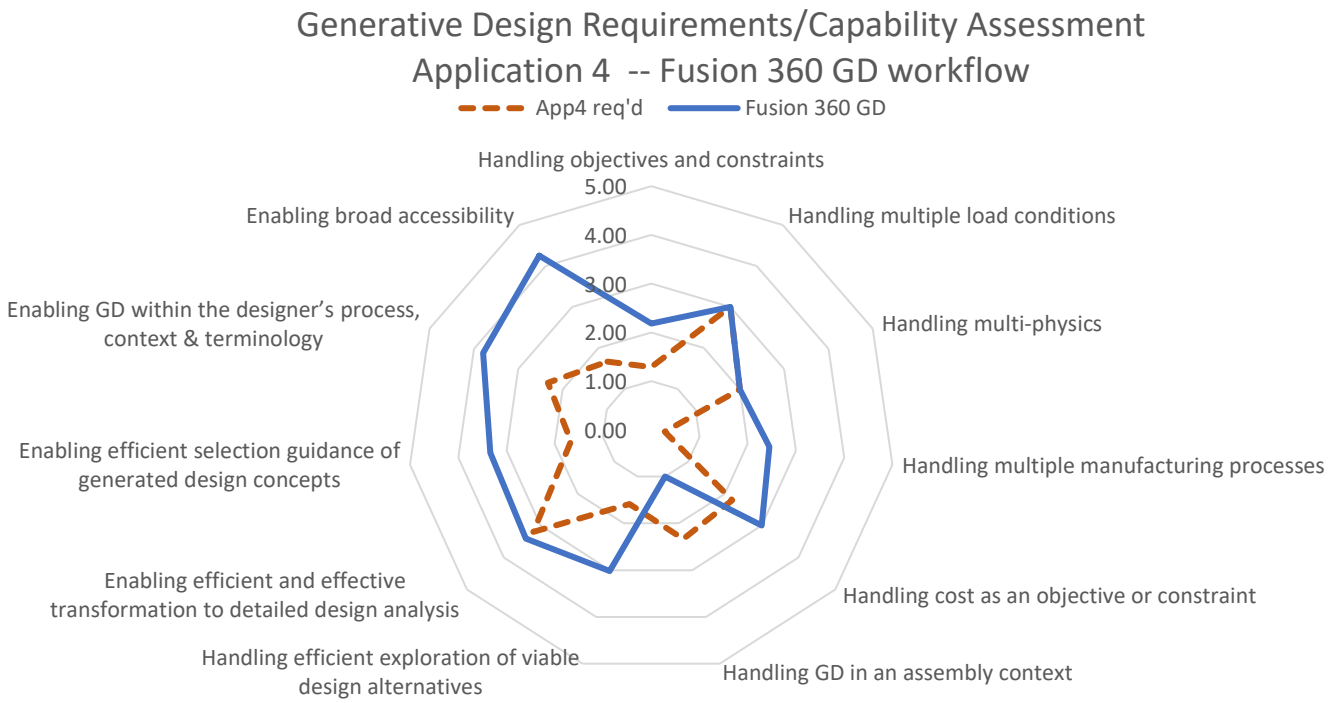


Suitability Indices for Sample Application 3	
Handling objectives and constraints	**1.69**
Handling multiple load conditions	**1.29**
Handling multi-physics	1.00
Handling multiple manufacturing processes	**8.65**
Handling cost as an objective or constraint	**1.36**
Handling GD in an assembly context	1.00
Handling efficient exploration of viable design alternatives	**1.91**
Enabling efficient and effective transformation to detailed design analysis	**1.06**
Enabling efficient selection guidance of generated design concepts	**2.00**
Enabling GD within the designer's process, context & terminology	**1.63**
Enabling broad accessibility	**2.55**
Minimum Suitability Index	**1.00**
Mean Suitability Index	**2.19**

Based on the Sample Application 3 requirements and the suitability analysis, the Autodesk Fusion 360 Generative Design workflow would be **"Clearly suitable"** for "Transmission case NVH optimization (case only)."

Sample Application 4: Transmission case NVH optimization (assembly context)

Application Description	**Transmission case NVH optimization (in assembly context)**
Goals/Objectives	minimize weight minimize radiated noise
Design Constraints	Maximum Stress below a specified level Natural frequency spectrum requirements
Physics Required	Noise & Vibration
Number Load Cases Required	Multiple load cases
Manufacturing Processes of interest	Casting
Materials to investigate	Steel Aluminum Cast Iron
Cost information required	Cost estimate of all design options Filter by cost
Target User	CAE analyst



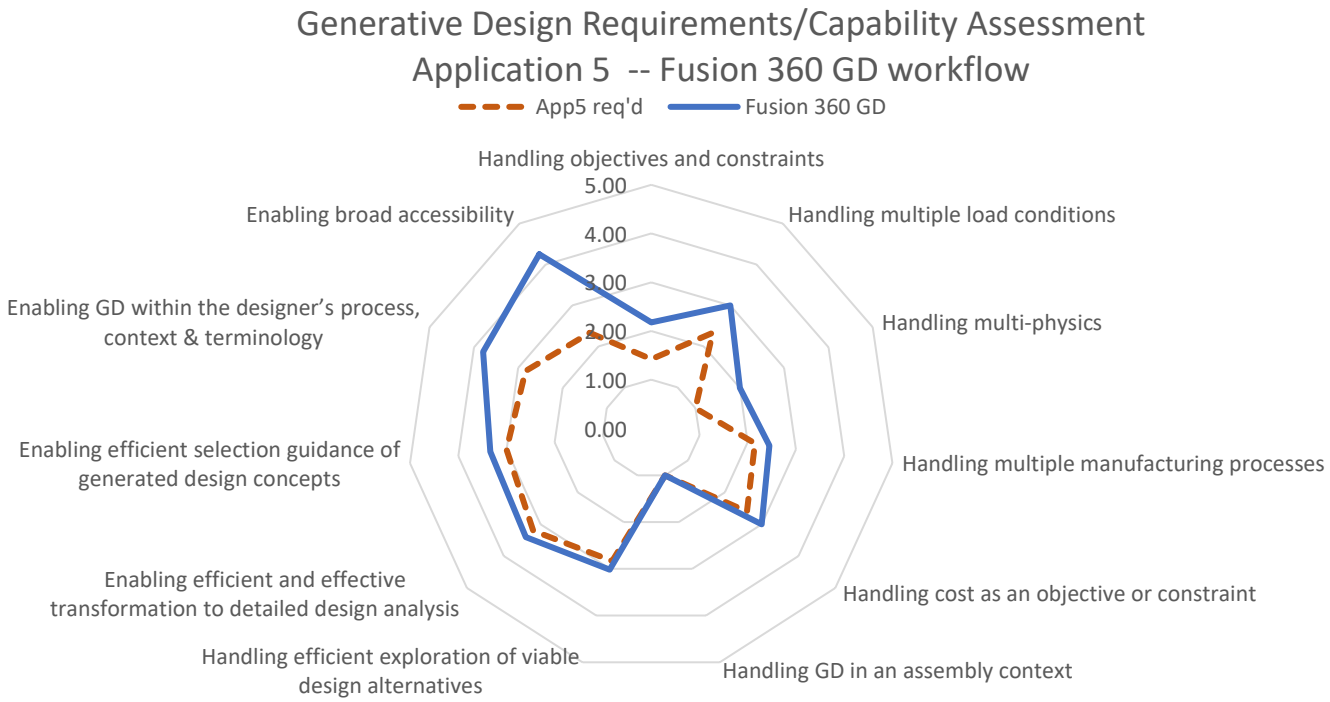
Suitability Indices for Sample Application 4	
Handling objectives and constraints	**1.69**
Handling multiple load conditions	1.00
Handling multi-physics	1.00
Handling multiple manufacturing processes	**8.65**
Handling cost as an objective or constraint	**1.36**
Handling GD in an assembly context	**0.43**
Handling efficient exploration of viable design alternatives	**1.91**
Enabling efficient and effective transformation to detailed design analysis	**1.06**
Enabling efficient selection guidance of generated design concepts	**2.00**
Enabling GD within the designer's process, context & terminology	**1.63**
Enabling broad accessibility	**2.55**
Minimum Suitability Index	**0.43**
Mean Suitability Index	**2.12**

Based on the Sample Application 4 requirements and the suitability analysis, the Autodesk Fusion 360 Generative Design workflow would be **"Possibly suitable and needs further investigation"** for "Transmission case NVH optimization (in assembly context)."

A quick review of the suitability indices shows that the issue is related to Handling Generative Design in an Assembly Context. The Fusion 360 GD workflow does not currently support Generative Design in an assembly context, and the problem definition would have to be remapped to a component (part) based design scenario. If the assembly context is a requirement, and the problem cannot be remapped to a component (part) based design scenario, then the Fusion 360 GD workflow is not suitable for this application.

Sample Application 5: Exploring Manufacturing Processes

Application Description	**Exploring Manufacturing Processes to minimize Manufacturing Costs for Medium-Large Production Runs**
Goals/Objectives	Determine the lowest cost of manufacturing while maximizing Safety Factor
Design Constraints	Minimum Natural Frequency
Physics Required	Linear Stress analysis Vibration
Number Load Cases Required	Multiple load cases
Manufacturing Processes of interest	Additive Multiple subtractive processes Casting Forging 2 axis Cutting 2.5 axis milling 3 Axis milling 5 axis milling
Materials to investigate	Steel Aluminum Cast Iron Titanium
Cost information required	Cost estimate of all design options with setup & production volume costs Filter by cost
Target User	Design Engineer

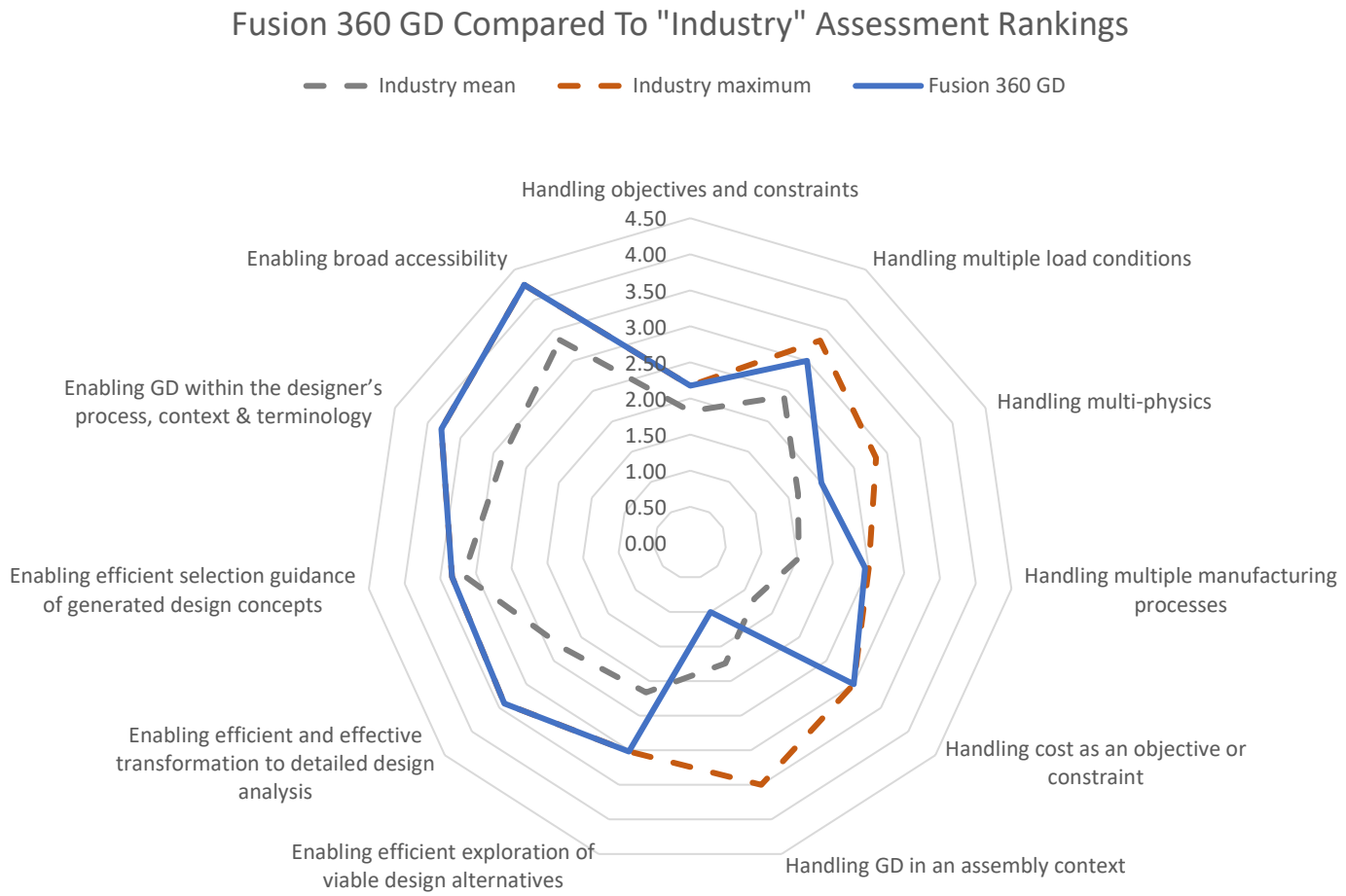


Suitability Indices for Sample Application 5	
Handling objectives and constraints	**1.54**
Handling multiple load conditions	**1.29**
Handling multi-physics	**2.00**
Handling multiple manufacturing processes	**1.14**
Handling cost as an objective or constraint	**1.15**
Handling GD in an assembly context	1.00
Handling efficient exploration of viable design alternatives	**1.07**
Enabling efficient and effective transformation to detailed design analysis	**1.06**
Enabling efficient selection guidance of generated design concepts	**1.11**
Enabling GD within the designer's process, context & terminology	**1.34**
Enabling broad accessibility	**1.82**
Minimum Suitability Index	**1.00**
Mean Suitability Index	**1.32**

Based on the Sample Application 5 requirements and the suitability analysis, the Autodesk Fusion 360 Generative Design workflow would be **"Clearly suitable"** for "Exploring Manufacturing Processes to minimize Manufacturing Costs for Medium-Large Production Runs."

Fusion 360 GD Workflow Assessment Summary

The following illustrates the comparison of Fusion 360 GD workflow to the "industry" rankings covering eleven (11) Generative Design workflows, including Fusion 360 GD plus ten (10) others.



- **Fusion 360 GD** was classified as a **"market leader" in 8 Key Capability Areas.**
  - "**market leader**" classification occurs when the workflow ranking is at or very near the maximum rankings across the industry for the Key Capability Area.
- **Fusion 360 GD** was classified as **"Strongly Competitive" in 2 Key Capability Areas.**
  - **"strongly competitive"** when the workflow ranking is below the maximum rankings but above the mean rankings across the industry for the capability area.
- **Fusion 360 GD** was classified as **"Not Competitive" in 1 Key Capability Area.**
  - **"not competitive"** classification occurs when the workflow ranking is below the mean rankings across the industry for the capability area.