NORDDESIGN CONFERENCE
REYKJAVIK, ICELAND, 12-14 AUGUST 2024

Design for Inspectability: Identifying Its Requirements and Underpinning Enabling Technologies

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Abstract: This paper presents Design for Inspectability (DfI), a type of design for X which seeks to enable the design of parts of high value such that they may be more easily and effectively inspected by non-destructive evaluation (NDE) methods during manufacture and operation. To enable steps towards its realisation, the contribution of this paper lies in: (1) outlining the nine key requirements of DfI based on the needs of the NDE techniques; (2) identifying how design processes could be amended to embed DfI; and (3) proposing four enabling technologies that could underpin DfI.

Keywords: Design for X; Design for Inspectability; Non-Destructive Evaluation; Design Methodology; Artificial Intelligence (AI)

1 Introduction

The design of products and structures has a huge impact on their overall lifespan, from manufacturing and operation to decommissioning and recycling. Design methods such as design for assembly and design for manufacture have proven its importance on reducing cost and improving part quality (Boothroyd and Alting, 1992). Design for inspectability is an engineering design principle proposing that inspection methods should be embedded early in the design process such that inspection can be easily and reliably carried out for parts in qualification, with the possibility of considering in-operation inspections.

For structural parts requiring inspection, the principal design drivers are often those imposed by standards, loading requirements and economic constraints ensuring they can remain safe and economically viable during the life of the product. Inspection and maintenance requirements are typically considered much later in the design process meaning that many part features are fixed and often poorly selected to such that they cannot be easily and effectively inspected. This can reduce a part's lifespan significantly as it is impossible gain real-time insights into the structural health of a product.

Inspection of structures and high-value products are considered in some standards, e.g. for pressure vessels API 510 (API, 2022) considers the need for wall thickness measurements (from ultrasonic measurements) and API RP 572 (API 2023) provides details about how to do the inspection. However, these requirements do not directly impact the design of a part. Reasons for this are multifold, for example: (1) unknown maintenance requirements by the designer; (2) poor communication with quality control teams; (3) standards lacking information about the inspection needs; and (4) increase in production costs as a result of adding more constraints to the design. Nonetheless, the potential benefits from incorporating inspection requirements in the design stage could comprehend longer in-service products and structures, which could have a great impact on decreasing the cost of the product through life, in spite of increased production costs in the short term.

The inspection of structural components can be addressed through multiple techniques: ultrasonic inspection, eddy current inspection, radiography, infrared thermography, visual inspection, or dye penetrant (Gupta et al., 2022). These techniques are catalogued as non-destructive evaluation (NDE) techniques and have a crucial role in ensuring the integrity and safety of the products being inspected. However, inspecting structures has a major impact on many industries as it requires suspending the operation of the part in order to carry out these necessary activities. Designing more inspection-friendly products has the potential to minimise this impact and enable longer in-service components. However, this area of research has not sufficiently addressed with existing work looking at specific instances such as the design of bridges (Colford et al., 2019; Vogel and Schellenberg, 2012) or additively manufactured components (Mahan et al., 2022), but no design framework has been proposed that deals with Design for Inspectability (DfI) holistically. Although inspection information is often specified in a Product Design Specification, there are no systematic approaches to qualify inspection requirements regarding elements such as performance, costs, standards to work. This provides the case for development of a Design for X (DfX) technique which is integrated early in the design cycle.

The contribution of this paper is threefold and lies in: i) the identification of the requirements of design for inspectability; ii) the proposition of how design processes could be amended to facilitate design for inspectability to be considered through the life of a product; and iii) the identification of underpinning technologies (Ux) for a holistic Design for Inspectability framework with justification of how they are able to meet the requirements of DfI.

The remainder of the paper is structured as follows: Section 2 introduces the state of the art in design and current NDE processes; section 3 discusses current inspection protocols, illustrated by use cases; Section 4 proposes new design approaches to embed DfI; Section 5 identifies underpinning technologies that could enable DfI; finally, Section 6 provides concluding remarks and avenues for further work.

2 Background

2.1 The Design Process, Design for X (DfX) and Design for Inspectability

A common design process employed in engineering design is the prescriptive design methodology proposed by Pahl and Beitz (Beitz et al., 1996). This gives four key stages to the design process: i) Clarification of task; ii) Concept Design; iii) Embodiment Design; and, iv) Detail Design. As one proceeds through the stages of the design process, the cost of design changes increases exponentially greatly reducing the possibility for alternatives. Currently inspection is often considered as part of or after the detail design process, meaning that design changes are for the most part not possible to accommodate better inspectability of designs.

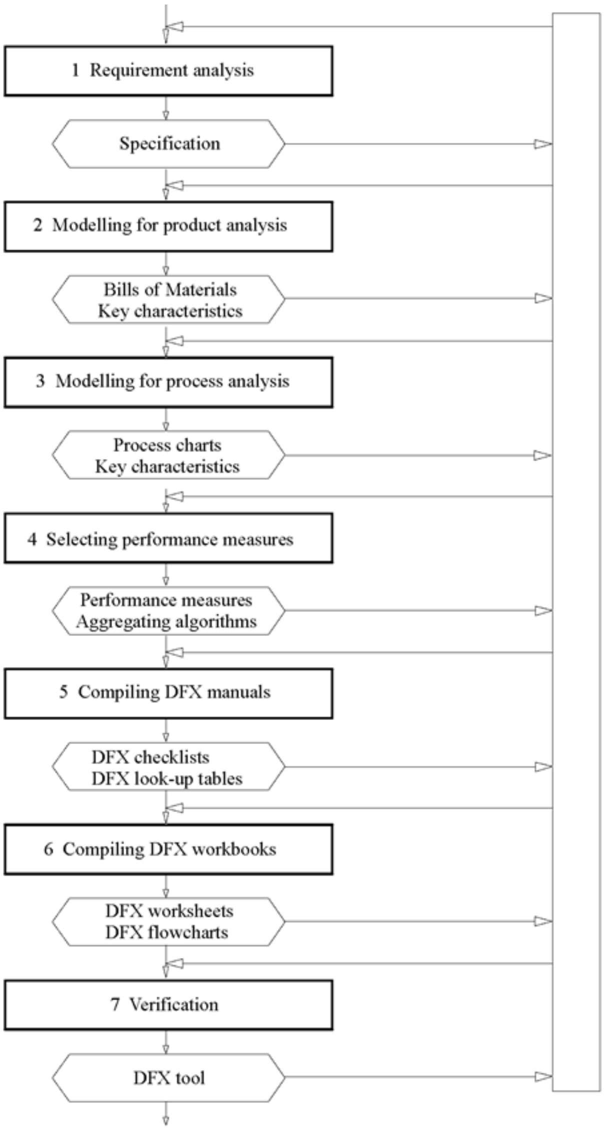

Figure 1. Procedure for developing DFX tools using the ‘DFX Shell’ (Huang 1996)

Design for X (DfX) represents a range of product development techniques that can be applied to achieve improvements in quality, costs and cycle times. These can yield three types of design approaches as outcomes: 1) guidelines as bullet pointed statements to advise designers of what to do and what not to do; 2) guidelines with pictorial representation; or, 3) a systematic approach to evaluate a design usually very early in the design cycle, post-concept, and provide measures of performance against knowledge collated about good or poor practice in the discipline. The latter represents the most challenging element to develop following the DfX research methodology closely, which includes validation. The process for developing DfX approaches is depicted in Figure 1. Some established DfX methods include Design for Assembly (DfA), Design for Manufacture and Design for Additive Manufacture (DfAM) (Huang and Mak, 1997). The application of these different methods have huge impacts on product development processes such as 84% reductions in failure costs through use of design for six sigma at Motorola, and 45% cost reduction of assembly through application of DfA (Booker, 2012). The effectiveness of different DfX is greatest if they can be implemented earlier in the design process, with this typically occurring at the embodiment stage of the design.

DfX shell is a framework that permits the development of effective DfX tools. It states that a DfX tool must do some of the following (Huang and Mak, 1997): i) gather and present facts; ii) measure performance; iii) evaluate whether a product or process is good enough; iv) compare design alternatives; v) highlight strengths and weaknesses; vi) diagnose why an area is strong or weak; vii) provide re-design advice by pointing out directions for improving a design; viii) predict what-if effects; ix) carry out improvements; and, x) allow iteration to take place. For the development of a DfI framework it is therefore essential that one or more of these factors are enabled by its enaction.

In literature, some design approaches for inspection have been proposed. Contributions have been made in the area of bridge inspection and design (Colford et al., 2019; Vogel and Schellenberg, 2012), qualitatively addressing the problem with soft requirements as having access to all concrete surfaces to carry out visual inspection. One interesting example that can be found in the literature, describes a process for DfI of additively manufactured components using pulse-echo ultrasonic inspection (Mahan et al., 2022). This work presents a series of ad-hoc restrictions that are applied to the design of the part and then are compared in terms of probability of detection, structural strength, and mass. Results suggest that the design requirements can be met, increasing the inspectability of the part while maintaining a good level of the structural integrity. Nevertheless, none of these works have explored methods to automatically optimise the design structures and products for accommodating inspectability (of more methods) and how that affects the whole lifespan of the designed product. Some contributions have looked at manufacturing conformity to reduce costs of manufacturing generally (Design for inspection, 2024) or at inspectable internal part volumes (Mahan et al., 2022). However, no existing work has holistically considered inspection from angles of both part verification and validation as well as in-life operation and maintenance.

An effective DfI implementation would be required to provide value through avenues as defined by DfX shell (**R1**), and also be implementable early enough in the design process such that it can affect design change (**R2**).

2.2 Structural inspection

In order to determine principles that would underpin DfI, it is first necessary to provide an overview of structural inspection methods. Inspecting high-value products and structures can be addressed by multiple techniques. It is worth distinguishing between continuous and discontinuous types of inspection. Continuous monitoring, also known as structural health monitoring, uses permanently installed sensors that acquire information throughout the lifetime of the structure. These sensors are typically used for early detection of damage and defects but provide low level of detail information about the defect itself such as accelerometers or strain gauges. On the other hand, NDE techniques are deployed intermittently at a given frequency to ensure the structural integrity of the most critical elements. NDE provides a greater level of detailed information compared to structural health monitoring. Since NDE is most widely adopted by safety-critical and high-value industries, it constitutes the type of techniques discussed in this section. The high value nature of these applications justifies the development of specific DfI approaches.

The applications of NDE are multifaceted and are used from manufacturing stages to ensure quality finish and defect-free products to the inspection of structures during their operation. Among all the available NDE techniques, a few can be highlighted due to their degree of adoption and quality of the inspection results. Examples of these techniques are listed below and illustrated in Figure 2:

- Eddy currents (Sophian et al., 2017). Eddy current testing consists of a coil that induces eddy current in the sample through electromagnetic coupling. Any significant change in the magnetic field may represent a discontinuity and therefore a defect. This NDE technique is applied for defect detection and characterisation for instance for corrosion, remaining wall thickness measurements, and coating or insulation measurements.

- Radiography (Menaria et al., 2019). This NDE technique works through the radiation of X-rays that go through the specimens and are captured in X-ray film. Thicker and denser areas will attenuate more energy and therefore defects or discontinuities are captured as darker areas in the film. This technique is used typically to inspect hidden defects or occlusions, however it has difficulties dealing with measuring the depth of the defects – hence this is a technique usually adopted for defect detection.

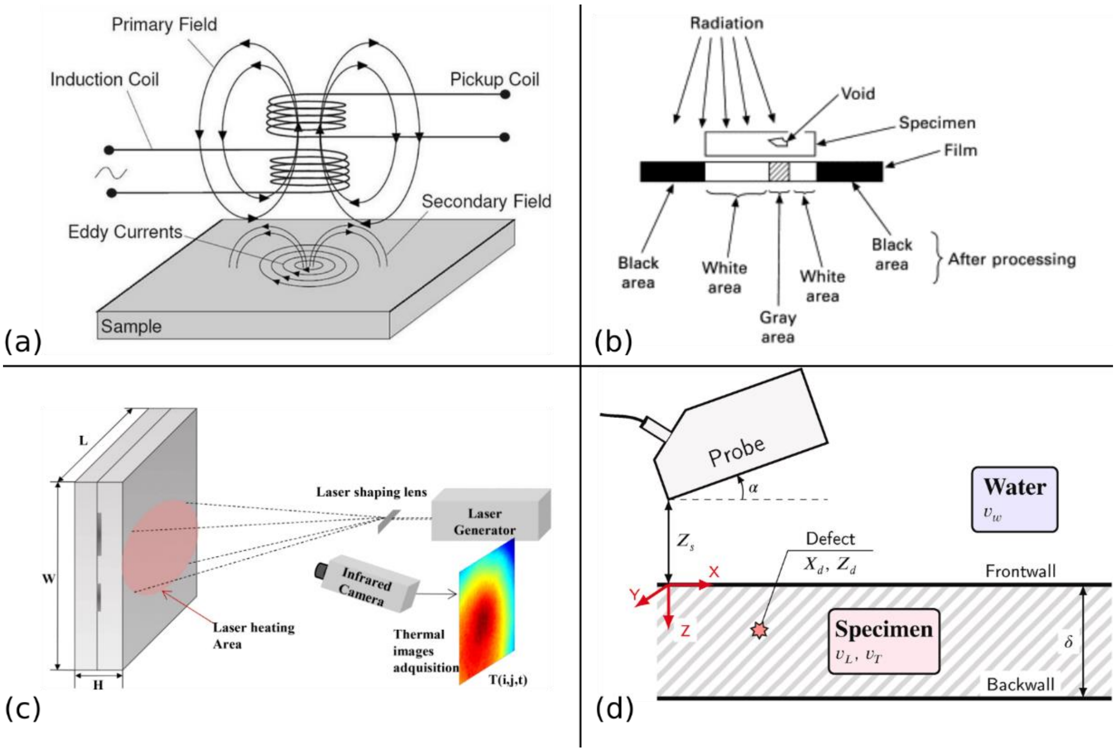

Figure 2. Panel (a): eddy current testing (Hwang et al. 2015). Panel (b): diagram of radiography testing (Zappia, 2010). Panel (c): infrared thermography testing (Liu et al. 2019). Panel (b): Immersion array testing configuration (Cantero-Chinchilla et al., 2023a)

- Infrared thermography (Khodayar et al., 2016). This technique works by capturing the radiation pattern of a specimen after being heated (active thermography). Defects are captured as a great discontinuity in the thermal field. Similarly to radiography, this technique is typically used for detection purposes as quantitative measures such as defect depth are difficult to be obtained. Applications include damp patches detection in concrete and masonry bridges and composite defects (e.g. delamination) detection.

- Ultrasound (Chen, 2007). This is probably the most widely used technique due to their relatively low cost of implementation and high level of resolution. Ultrasonic testing can be applied through different modalities depending on the sensor and actuation. For instance, pulse-echo testing requires a transducer that actively emits and receives an ultrasonic wave in the same point. This modality is typically used for measuring wall thickness measurement in pressure vessels or pipes that can be affected by corrosion (Cantero-Chinchilla, et al. 2023b). Array imaging is another modality that has been widely adopted due to its capability to resolve fine elements inside a thick specimen, enabling material characterisation and defect detection and characterisation (Drinkwater and Wilcox, 2006). Applications include weld inspection or material grain orientation estimation. Main issue is related with the fact that an array probe is needed to perform this technique which has to be either in contact or submerged in a liquid to avoid energy dissipation. Lastly, it is worth highlighting a novel array imaging technique which mimics traditional array probes through a detection and a generation laser that moves around the specimen (Stratoudaki et al., 2016). This is a promising technique that enables non-contact inspections for complex shaped surfaces or hazardous environments without human intervention, but it is still in the early stages of development.

The use of the NDE techniques listed in Section 2.2 targets either the material characterisation or defect detection in different stages: manufacturing and/or in-service. To ensure quality control in manufacturing, these processes are applied using tailored inspections of the produced parts that adapt to their shape – e.g. inspecting carbon fibre pieces with curved complex surfaces using wheel-array sensors (Brotherhood et al. 2003). For in-service inspections, these techniques are typically deployed by either a trained operator or an unmanned vehicle that tries to inspect the most critical elements of the product or structure. This means that unless there is some gap or aperture to access the inspectable element, the inspection of the specimen is rather difficult if not impossible to carry out at some times. In addition, difficult access usually means longer shutdown times of costly assets – e.g. an airplane or a nuclear reactor.

Good inspections mean high probability of detection and low false alarm rates. This can be achieved via several means, for instance: (1) maximising signal-to-noise ratio through averaging, i.e. repeat measurements and average to minimise random noise; (2) applying appropriate processing techniques – e.g. total focusing method in the ultrasonic array imaging technique (Drinkwater and Wilcox, 2006); and, (3) accessing the inspectable product in a way that optimised sensing strategies can be applied (Cantero-Chinchilla, et al. 2023c). These strategies are often mixed and matched depending on the needs and spatial requirements of the NDE technology. In addition to maximise the chances of having a good inspection, basic geometrical and spatial requirements need to be met. These are typically related to the accessibility and finish of the part depending on the NDE technique being applied. The size of the sensor or element that will inspect the specimen is inevitably another element that needs to be met in order to enable the inspection. These can be synthesised into three further requirements for inspectability regardless of the NDE technique:

- **R3** – Appropriate surface finish and internal structures (e.g. geometrical dimensions and tolerances) to allow the application of appropriate NDE techniques;
- **R4** – Accessibility in situ to critical points of inspection without substantial disassembly being required; and,
- **R5** – Repeatability to enable consistent measurements across time such that changes in structural integrity can be identified.

3 Current inspection protocols

Current inspection protocols are ad-hoc as design stages are addressed in a sequential manner without feedback from the successive stages (as shown in Figure 3). Inspection is generally considered in the quality control stage which is secondary to product design. This means that inspection protocols are developed around a pre-defined design which has been developed without consideration for its capacity to be inspected. By this point in the design process, as the cost of change is typically higher, design changes aren't made to accommodate for improved inspectability. This can result in parts that are for example, optimised for manufacturability but are extremely poorly designed for inspectability resulting in time intensive inspection being required to validate parts post manufacture which greatly increases part cost. An industrial use case to exemplify this is that of aerospace panels with complex elements such as butt-joints, where lack of design for inspection results in part validation taking two times longer than the manufacturing process.

This can be illustrated by the design of a pressurised tank in the context of an oil & gas power plant. The design of this element typically is addressed through the requirements specified in the regulations (e.g. strength and stress requirements) and the client's needs that need to be met (e.g. how much liquid it needs to store and how much pressure it needs to withstand). In this stage, structural, geometrical, geotechnical and even environmental factors are taken into account and incorporated in the design of the structure. Critically, the fundamental design of the pressurised tank is defined within this stage without consideration of how it will be inspected later on.

Once the structural and geometrical design of the tank is specified (therefore at the detail design phase according to Pahl and Beitz, refer to Section 2), this goes into the quality control team, who are responsible for ensuring that the quality of the structure complies with certain regulations, so a set of techniques for this are considered (e.g. eddy current testing or ultrasonic testing in welds). If the quality control team spots a potential issue that will happen when validating and commissioning the tank, this is communicated to the design team to try and accommodate it – e.g. in the form of a geometrical feature that will impede the inspection and therefore needs to be removed. However, this communication is often not very well established in many companies, which leads to issues in the inspection at the quality control stage which, in the worst case, can result in the design and production of parts that subsequently cannot be qualified.

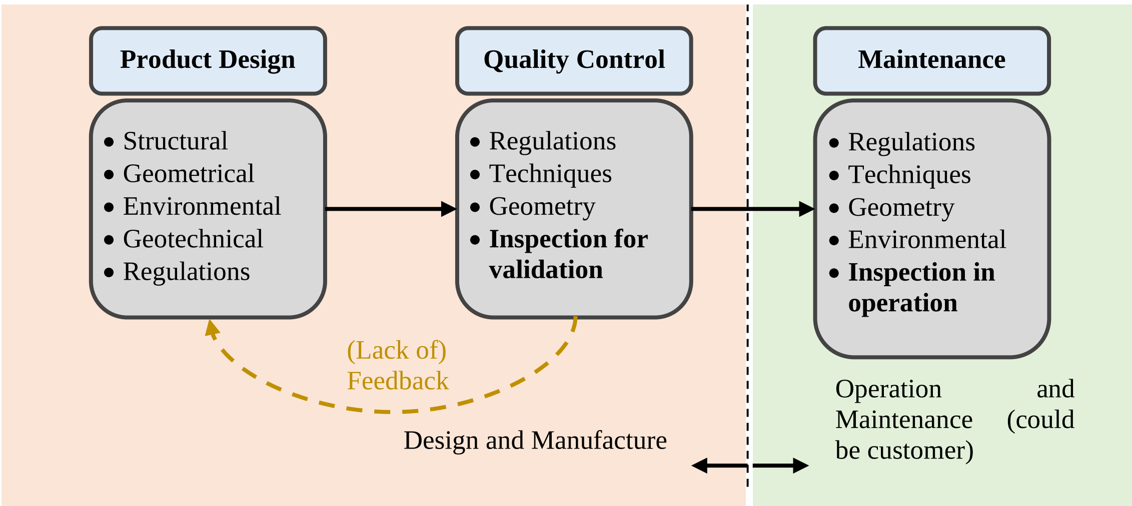

Figure 3. Schematic of the current inspection protocol. Inspection is a dis-connected activity considered independently by quality control and maintenance teams. It is not typically considered in product design stages

Once the tank is designed and its quality assured, it can be commissioned and then operated. Operation, including associated maintenance and required inspection, of such asset is carried out, often by the customer. In a similar manner to the impact to the quality control processes, the design will have a large impact on the required maintenance of the structure dictating the ease at which critical areas can be accessed for inspection and the amount of time the asset needs to be out of service to undertake inspection. Consideration of these factors at the product design stage can greatly improve the asset's maintainability, but given the product design is often carried out by a different entity to the one that operates and maintains it, there can be little incentive to do so.

The illustrative example shows the importance of having an integrated design process as required inspection (in the quality control and maintenance stages) is heavily impacted by the product design stage. Quality control and maintenance happen at a similar location (the tank is deployed always at one location), which makes it easier to incorporate the inspection needs in the product design stage. However, many other engineering products are inspected at manufacturing and operation stages in very different environments. For instance, a composite panel for the wing of an airplane can be carefully inspected when manufactured with great accessibility, but when deployed in the plane, the inspection needs to be addressed from a different perspective and even different techniques. One could use ultrasonic wheel-array probes at manufacture with good resolution and coverage; but when it is mounted in the airplane this technology cannot be used for logistics reasons and one may either need to use lower quality inspection or overlay multiple time-consuming inspections.

Moreover, from a regulatory perspective, there are cases where the compliance of a standard automatically contradicts another. This is highlighted by the UK Office for Nuclear Regulation (Carter, 2020), who state that components designed according to ASME III (ASME, 2023a) often cannot meet the ASME XI (ASME, 2023b) NDE requirements. The added value of easy-to-inspect components in safety-critical industries is highly appreciated and represents an area of interest to regulators.

Through analysis of existing inspection protocols and how this plays out in real use cases it is shown that the product design stage has drastic impact on a part's inspectability in qualification and through life in operation. These permit elucidation of four further requirements of design for inspectability.

An irregular geometry of the product or part that makes it difficult to inspect through in-contact ultrasound, **R6** is therefore for a part to have regular geometry facilitating inspection. Manufacturing parameters must be optimised to enable inspectability **(R7)** otherwise, for example, grain structures in additively manufactured metals can cause coherent noise in ultrasonic images that can potentially hides other defects. Materials must be selected that are suitable for a specific inspection method (**R8**), this is critical as, for example, poor choice of materials that enable little interaction with eddy currents or that attenuate the ultrasonic waves, decreasing the signal-to-noise ratio of the acquired data. Lack of communication between product design, quality and operation teams results in inspectability not being embedded with products, R9 is that DfI must facilitate effective communication between design, quality and operation teams to enable the impact of inspectability to be understood and embedded in a design.

4 Proposing a new Design for Inspectability (DfI)

This particular type of DfX addresses the concerns of quality assurance or control and incorporates the relevant requirements in the design process. Although this is a complex design constraint, it is typically incorporated in safety-critical applications so the products can be inspected after manufacturing. This ensures that the products can be commercialised or sent to the customer ensuring its quality. However, these products are often parts of a larger assembled one – e.g. a composite panel that goes into the wing of an airplane. The inspection procedures will naturally vary depending on the stage of the product – i.e. when it is manufactured or when it is in operation. Hence, incorporating the additional requirements that may arise from the maintenance inspections when the product is in operation may have a positive impact. This can be in the form of faster inspections that enable shorter shutdown times and therefore higher revenues.

Here we are proposing an extended vision of DfI whereby inspection at both manufacture and operation are considered and incorporated in the design process. This could be addressed as follows (see Figure 4):

- Parallel design processes. All requirements from the classical design process (manufacture, geometrical, structural, etc.) need to be considered in addition to those coming from the inspections of the product at both manufacture and operation (maintenance) stages. This approach would require a computational tool that is able to create designs that meet the requirements. Whilst a tool like this is yet to exist, the capabilities required are within the scope of what is feasible with current generative design tools. This is a challenging approach to achieve given that everything would need to be integrated in one platform, but the potential benefits are important: (1) minimum impact in the current design protocols, and (2) long-term, improved, inspections (e.g. having optimal probability of detection) that lead to more reliable decision-making.

- Iterative design process. The added requirements from the inspections that are carried out at manufacturing and maintenance stages are incorporated in an iterative manner, that could be automated or conducted manually. This could be through a computational platform that proposes product designs and the quality assurance and maintenance teams provide feedback. The iterations continue until all the aspects from the design (see Figure 1) are met. The feedback can be provided by the personnel in each team (although rudimentary and inefficient) or automated in a software platform that goes through several stages and stores the input from each of them to reinitialise the process and propose a new product design. This process might be more appealing to implement given that little to no new tools would need to be developed, but more steps are effectively introduced in the design process.

It is important to highlight that by considering the proposed DfI protocols, we are going to increase burden at the design stage but providing a more competitive product that is going to be more easily inspectable (e.g. shorter shutdown times during maintenance stops) and therefore have a product that is cheaper for the client, considering long-term costs.

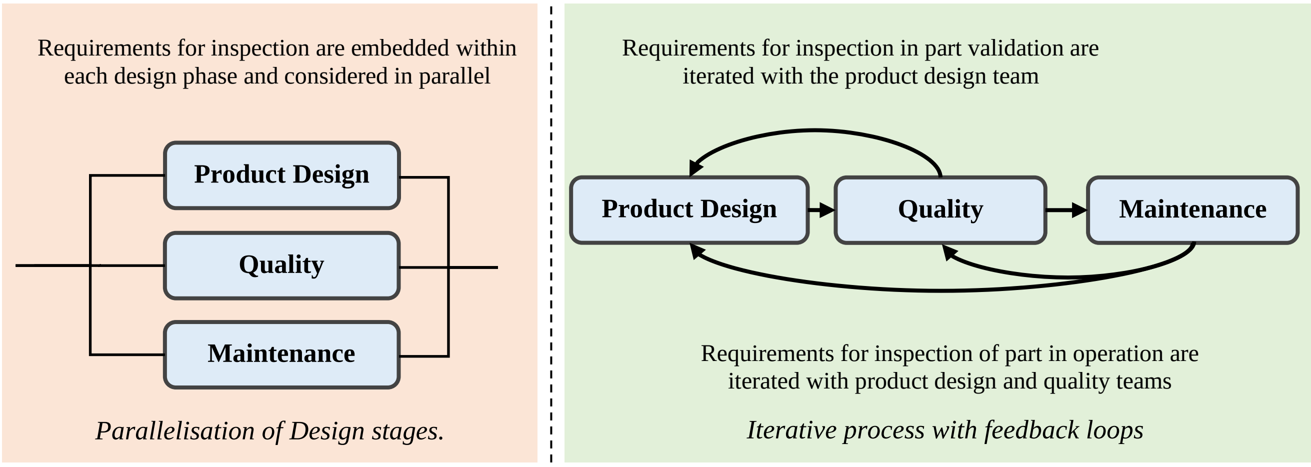

Figure 4. Proposed DfI processes: either by parallelising all the requirements into one design, or through an iterative process where input and feedback is incorporated from the inspection at different stages

5 Underpinning technologies and approaches

The practical implementation of the proposed DfI protocols require the use of novel process technology and working practices, which will ensure the efficiency and efficacy of these protocols. Table 1 presents an overview of which requirements of DfI are met by each underpinning technology. Justification is included in each subsection.

5.1 Generative design (U1)

One of the core elements by which DfI could be underpinned is generative design - ‘design approaches that use algorithms to create designs' (Caetano et al, 2020). Computational exploration of design spaces in generative design rapidly explore a wide range of designs permitting complete mapping of design spaces, either requiring a user to select a candidate design, or automatically selecting a final design based upon an objective function (Goudswaard et al., 2023). This approach provides an iterative framework that generates product designs that meet specific requirements or constraints. The process continues until the product design is optimised with respect to a predefined objective function. This is typically implemented through computational design tools that enable this optimisation in an efficient manner. Generative design tools are features of most commercial CAD packages including Fusion 360, CogniCAD, Solid Edge and Siemen’s NX. Generative design has substantial use in the design of structural components and optimised cooling. It is within the scope of current generative design tools that techniques enabling the generation of inspectability optimised structures could be developed.

Generative design tools can auto generate compliant structures. In so doing they upskill a designer and therefore provide value meeting R1. Incorporation of functional requirements provide value early in the design process (meeting R2) and their ability to create parts with constrained spaces permit GD tools to meet the requirements around surface finish and internal structures (R3); regular external geometries (R6); optimised manufacturing parameters (R7); and, with NDT friendly materials (R8).

5.2 Additive Manufacture (U2)

Considering the requirements of a good inspection throughout the lifespan of a product inevitably involves the consideration of geometrical aspects. This may be in the form of providing a sufficiently flat area to place a sensor or including certain gaps to be able and access the inspectable product. In this context, additive manufacture is one key element that will enable the realisation of the generative designs thanks its flexibility in terms of manufacturable geometries. Whilst an underpinning technology it is noteworthy to consider that the flexibility it affords is also a driver of a need for DfI. This technology is an enabler of a good accessibility (R4), e.g. for example allowing gaps so key structural hotspots can be accessed in an easy and safe manner. Additive manufacturing can also enable the creation of regular geometries that permit the optimal collocation of different sensing techniques – e.g. smooth surfaces for ultrasonic or eddy current testing (R6). Similarly, this technology can enable the optimisation of manufacturing parameters (R7) in order to produce materials that are easy to inspect with reduced data interpretation concerns - e.g. artefacts from grainy materials such as wire-arc additive manufacturing.

5.3 AI for design and inspection (U3)

Another technology that will be required in the DfI is AI. AI can help in several areas and it is currently being developed to do so: (1) generative AI through generative adversarial networks (Oh et al., 2019) which can be used for design guidance, idea generation and brainstorming; (2) data processing through convolutional neural networks and/or autoencoders that are used to enhance the quality of the data, e.g. denoising, image processing and selective signal processing (Cantero-Chinchilla et al., 2023a); (3) data interpretation, which is used for speeding up processes that are either manually addressed or require slow computational methods, e.g. for defect detection and characterisation from ultrasonic images (Cantero-Chinchilla et al., 2022). This technology when used in the context of DfI represents a set of extra tools for end-users who can exploit their products in the most efficient manner – e.g. through regular material macro- and micro-structures when coupled with generative design (R3 and R7) and consistent repeatability of the inspection results when implemented in the inspection protocols (R5).

5.4 Interdisciplinary working (U4)

One of the most important underpinning elements for DfI is interdisciplinary working – ensuring understanding across different domains with distinct expertise and dominant logics. When considering the success and failures of design tool implementation, (Booker, 2012) notes ‘who should be involved’ as a critical issue with champions being required to enable success with all relevant staff being trained appropriately to implement new design tools. Whilst the aforementioned paper considers implementation, it is equally necessary that all relevant stakeholders are considered in the requirements analysis stage (as defined by DfX shell) such that a design tool can be developed that addresses the broad needs of inspectability, not just those of an individual designer or group of designers.

Table 1. Cross-correlation of underpinning technologies and their ability to meet requirements of DfI

Requirements		**Underpinning Technologies**			
		Generative design (U1)	**Additive Manufacturing (U2)**	**AI for design & inspection (U3)**	**Interdisciplinary work (U4)**
R1	Provide value to design stakeholders	✓			✓
R2	Implementable early in product design stage	✓			✓
R3	Surface finish & internal structures	✓		✓	
R4	Parts are accessible in situ		✓		✓
R5	Repeatability in NDE measures			✓	
R6	Regular geometry	✓	✓		✓
R7	Optimised manufacturing param.	✓	✓	✓	✓
R8	NDT-friendly materials	✓			✓
R9	Effective communication between stakeholders				✓

Interdisciplinary working is key to successful implementation of DfI. Irrespective of the application of computational tools, if teams don't communicate and work together parts designed with inspectability embedded within them won't be realised. Provision of value (R1) requires interdisciplinary needs of stakeholders to be captured. DfI implementation early in the design process requires communication and elicitation of requirements across different stakeholders (R2). Accessibility of parts for inspection (R4) necessitates communication and understanding between teams in operations and product design. Creation of parts with regular geometry requires communication between design and production engineers (R6). Optimised manufacturing parameters for both functional part performance and inspectability and use of NDT friendly materials requires interaction between production, design and maintenance engineers (R7). Effective communication between stakeholders (R9) is addressed by interdisciplinary working as varied expertise and dominant logics are brought together such that mutual understanding can be reached.

6 Conclusions

This paper has proposed a new vision for DfI, which accounts not only for the inspection of parts in the manufacturing stage but also extends to the operation and maintenance actions. To this end, an overview of the general DfX and current protocols of DfI is presented. Nine key requirements (R1-9) are deducted for diverse NDE techniques and elements within the design process. Additionally, a set of four underpinning technologies and working practices (U1-4) are identified and their value is discussed, identifying their contributions to address the requirements.

The authors will adopt the proposed principles of DfI and demonstrate its potential in future work on several parts inspected through different NDE techniques, including ultrasonic imaging and eddy current testing.

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