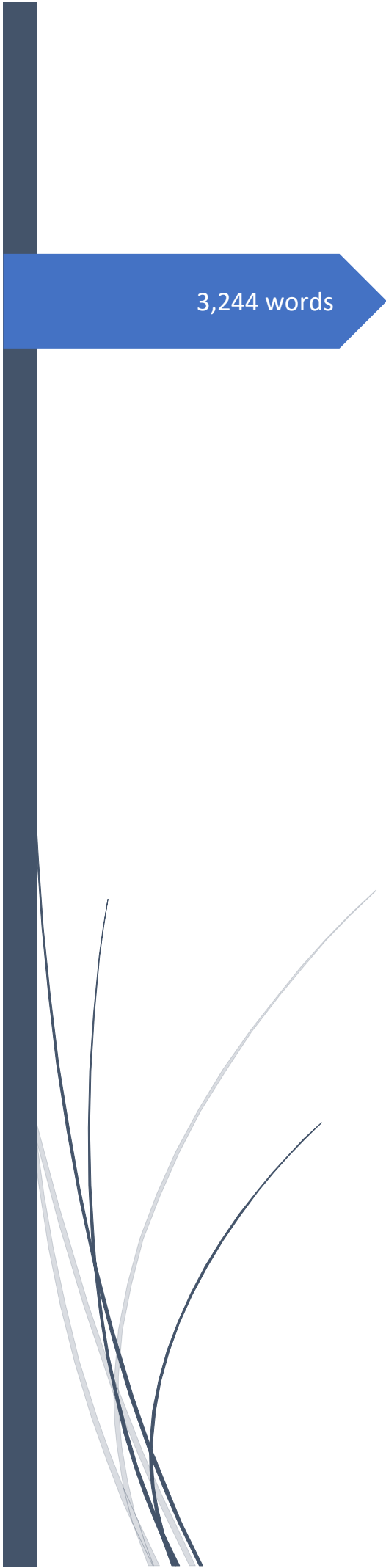


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3,244 words

Design For Industry 4.0

Reflective Essay

Nefyn Roberts
2009576

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Introduction

This essay will reflect on the ways in which new and emerging industry 4.0 manufacturing technologies can be applied to products and more specifically how they can apply to the automotive industry. Many of these technologies can be applied directly to the OEMs but also to Tier 1 and 2 suppliers in order to improve productivity, sustainability whilst also reducing costs. Wholescale attitudes to design can be re-thought in light of new design and production methodologies with an emphasis on batch manufacture and the modularisation of platforms.

A broad range of areas in which i4.0 methodologies can be applied will be reviewed. This will include design, simulation, validation, manufacture, assembly, the circular economy and also the societal impact of these new or emerging technologies being adopted.

Industry 4.0 in Manufacturing

The span in which industry 4.0 can be applied into manufacturing is extremely broad. If products within the automotive industry is considered, then the journey through manufacturing can be followed and the areas in which i4.0 can be applied can be reviewed.

Cloud computing can be used in the initial design stages to speed up the processing of generative designs and to also shorten the time taken to calculate for FEA analysis or CFD simulations, the cost of housing computers to run these complex simulations can be very expensive so outsourcing the processing to cloud based systems can be a net cost save for manufacturers (Simscale, 2017).

In manufacturing, The Cloud can be used to enable smart factory systems to communicate with one another to improve throughput and also anticipate potential bottle necks down the line (Silva, et al., 2021). AI based alert systems can be utilised to inform operators or engineers of potential problems and they can also be used to automatically schedule maintenance of key machinery (Meyer, et al., 2022).

Flexible Manufacturing

Advances in manufacturing processes have enabled manufacturers to become more flexible in their approach to prototypes and serial production parts. This can include newer and developing manufacturing methods such as additive manufacturing/3D printing (Ahangar, et al., 2019) and an emphasis on smaller bespoke batch scale products that can reduce investment in expensive hard tooling.

The move toward smarter factories, which have a flexible modular approach and greater connectivity and communication due to horizontal and vertical systems integration enable the eradication of work silos. By improving communication between systems, users and interfaces manufacturers can measure tangible benefits in productivity (Wheatley, 2019). In the automotive sector, improved and automated communication between OEMs and their suppliers (both Tier 1 and Tier 2), can help alleviate issues with supply chains (ERP Information, 2022).

Additive Manufacturing

The advancements in additive manufacturing and reduction in costs have revolutionised how manufacturers can approach prototype, batch and serial design.

A range of additive manufacturing methods are now available, polymers, metals and bioprinting are all now options. In the automotive sector polymer and metallic printing has been of particular use. Prototype parts or soft tools can be readily manufactured at a fraction of the cost and time impact compared to traditional methods to provide 'one off' solutions (van de Werken, et al., 2019).

The examples below by (Ahangar, et al., 2019), that are also relevant for the Automotive sector, provide an insight into the range of possibilities now available for designers and manufacturers to consider, in particular for the initial prototype stages to avoid significant cost outlays for tooling.

Binder Jetting

- Material - Sand and metal powder.
- Advantages – Low cost, fast, colour printing and no support structures required.
- Disadvantages – Low strength, requires post processing

Directed Energy Deposition

- Material – Metal and nylon.
- Advantages – Fast, can be used to repair existing products.
- Disadvantages – Expensive, slow, low resolution and required machining.

Material Extrusion

- Material – Hydrogels, Thermoplastics, Ceramics.
- Advantages – Colour, low costs, composite materials.
- Disadvantages – Slow, low resolution.

Powder bed fusion

- Material – Thermoplastics, metal powder, ceramics.
- Advantages – Strong, fast, no solvents needed.
- Disadvantages – Expensive, medium resolution, machining required.

Sheet lamination

- Material – Paper, ceramics, metal.
- Advantages – Low cost, composite materials, no support structures required.
- Disadvantages – Slow, material waste, delamination.

Smart Factories

Smart factories also offer increased productivity and adaptiveness in the manufacturing sector. In Automotive Manufacturing, Big Data, The Cloud in conjunction with the IIoT can be used to allow greater connectivity and communication within a production line (Silva, et al., 2021). This can allow messages to be fed up and downstream automatically and alter production speeds or output depending on conditions within the factory or machinery. Smart robots can also be used to navigate the factory autonomously to deliver parts or tools to workstations JIT to avoid unnecessary storage line side and potential incorrect assemblies (Technology.Org, 2019). AI can also be utilised to recommend maintenance schedules, based on usage and throughput of key machinery, to prevent unexpected down time (Meyer, et al., 2022).

Smart factory methods have also successfully been adopted in sorting and depot business. Online supermarket (Ocado) uses a smart factory dubbed 'the hive' where the 'floor space' is manned completed by robots that move in 3 dimensions (Warehouse Automation, 2022). This allows a greater utilisation of space and efficiency in movement, thus reducing waste. This type of system

could also be adopted in the automotive sector in regard to parts storage areas, whilst JIT is still an important aspect of the automotive business model in terms of keeping storage costs low and the space taken minimal (Banton, 2022). Experiences from the pandemic have required reassessment by OEMs on how much stock they should hold (AM Online, 2022), by adopting efficient 3D space utilisation more parts can be efficiently stored and used when required whilst taking up a minimal footprint.

Societal impacts of Design for Industry 4.0

The societal impacts of adopting industry 4.0 technologies should not be underestimated. It is important for industries and government alike to recognise the key change that will follow large scale uptake of these methodologies. It is likely the emergence of AI based systems, The Cloud and the Internet of Things will make certain jobs obsolete (Hahn, 2023), an example of this in the automotive sector would be taxis.

Companies such as Waymo (Alphabet) and Uber are investing in technologies and business models that utilise ADAS level 5 systems (Synopsis, 2022), which may in turn push traditional taxi drivers towards obsolescence. This shift toward adopting i4.0 in the use of vehicles will radically change both the taxi industry but also the concept of car ownership. Once automated travel becomes more common place, the business model of selling or leasing cars to people and for them to be able to drive that vehicle could become a thing of the past. Instead in future people may choose to not own vehicles and instead use automated car hailing or leasing apps (McIntosh, 2021).

This wholesale change in one industry thanks to i4.0 gives a glimpse into the radical changes that can occur by adopting these technologies. Governments, industries and society will need to adapt to both job losses in some sectors but also job opportunities in new and emerging markets. Upskilling of people in order to make them adaptable and agile to fast changing economies will be vital, something acknowledged by the Welsh Government in their Wales 4.0 strategy to manage these changes (Welsh Government, 2019).

Workforce impact.

The impact of adopting i4.0 related technologies and methodologies will also be significant to existing and future workforces. Industry 4.0 developments likely to create more jobs than they replace (Hahn, 2023), however existing workforces will need to adapt to new roles.

Therefore, upskilling the workforce will be imperative for future employability. As the (Welsh Government, 2019) explain, this could include transitioning people from roles susceptible to automation such as retail and transport into areas not yet readily automated such as health and social care, teaching. Another move could be to re-train workers into the jobs created in new and emerging industries thanks to the recent technological breakthroughs via i4.0 (Newton, 2022).

Product design and Development

If the wishbone of a car is taken for example, at the initial concept stage, generative design can be applied to provide the optimal shape in the given parameters - weight, materials, forces and design envelope. When The Cloud is used in conjunction with generative design it provides designers with multiple iteratively optimised designs in a short amount of time, allowing designers to focus on other aspects with the creation cycle (Jain, 2020). The best options can then be filtered and compared against one another. Due to the computing power of The Cloud, different testing parameters such as load forces or material selected can be quickly simulated on these generatively designed parts and compared against each other.

Engineers can then determine the best design based on it meeting design criteria such as cost, weight and achieving a minimum safety factor. It is worth noting that as useful a tool as Generative Design is, the solutions provided are only as good as the information inputted and with clearly defined parameters (Jain, 2020). Whilst AI plays an important role in crunching the numbers to provide design solutions, it is not yet advanced enough to think like a human and abstractly define what the parameters should be. Therefore, GD should be seen as a useful tool in an engineer's arsenal rather than a replacement for skilled designers.

Validation testing and Quality Control

Industry 4.0 offers opportunities for manufacturers to ensure heightened quality control and testing. As the price of computing comes down the power of processing increases, defined by Moore's Law (Tardi, 2022), so too can simulated testing or FEA analysis. In the automotive industry in particular FEA is frequently used to simulate the strength of components such as suspension arms to ensure that they will adequately perform on vehicles. Whilst these simulated results are still validated physically, the improving accuracy of these simulations offers to provide greater data feedback to engineers in the initial development stages. Whilst the cost of computing has come down, it is also worth noting that the complexity of simulations has increased as software strives to become more and more accurate, this is where cloud-based services come in particularly useful for businesses as they can still run these complex simulations without the need for the upfront high performance computing costs (Ansys, 2022).

Quality control can also be benefited by i4.0, using smart sensors such as cameras or microphones in conjunction with AI software can help detect faults in machinery or products and monitor lines and output live (Taylor, 2023). As (Lee, et al., 2017) show big data can be used for predictive maintenance, combined with audio systems, this can be used to detect tool wear, this can alert engineers and line operators to change tooling sooner to prevent scrap. Likewise, camera systems used in conjunction with computers and software/programmes (Chalifoux, 2018) can be used to detect faulty parts on the production line, spotting issues sooner and removing them earlier by alerting an operator to the fact.

Manufacturing phases

Generative design and additive manufacturing can offer a greater degree of flexibility in the design and prototype manufacture process when compared to traditional methods.

Concept Phase

In the Concept phase, generative design can re-calculate and remodel designs digitally if parameters such as design envelope, material, cost or loads and forces are required to be changed. This can save engineers hours in design, calculations and processing time as the cloud enables faster iterative permutations allowing optimal solutions to be determined sooner. This can be particularly useful to engineers in the design and prototype stages, as designs can be manufactured and tested within hours (Form Labs, 2019). Additive Manufacturing also provides design opportunities that were not available using traditional methods of manufacture, giving engineers greater freedoms so long as the parameters described by (Hubs, 2022) are adhered to.

	Supported walls	Unsupported walls	Support & overhangs	Embossed & engraved details	Horizontal bridges	Holes	Connecting /moving parts	Escape holes	Minimum features	Pin diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused deposition modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereolithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective laser sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct metal Laser sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

Figure 1, Design Parameters and constraints for additive manufacturing (Hubs, 2022).

Batch Production

The decreasing cost of additive manufacturing and the speed of the process can make it a more cost effective than traditional formative or subtractive methods. To relate this to the automotive sector, parts that would previously need tooling, costing significant time and money can now be printed within a few hours and fitted to a working prototype (Form Labs, 2019), if successful this can also be upscaled to a small batch level for prototype build phases. This can allow the manufacturing teams to assess fitment and assembly feasibility before money is spent on both hard tooling for serial builds.

As (Form Labs, 2019) show, end use after-market parts can also be manufactured in small scale for relatively low cost (compared to traditional methods) to keep producing replacement parts that are no longer stored by OEMS.

IA.0 can also enable mass customisation of core products. If the cabin in a vehicle is used as an example, the main features such as the centre console can remain hard tooled, however trim parts such as air vents and gear lever surrounds and door cards can be altered to suit small bespoke production runs. For example, a 'sportier' version of a vehicle may require a different colour or material of trim. Additive manufacturing can be used to support these batch production requirements without the need for hard tooling.

Design for the Circular Economy

It is important that as i4.0 technologies are adopted that the environment is also considered. By designing for the circular economy, the resources used in products can be reduced and the products themselves can be re-used or recycled. Designers should also consider ease of disassembly and maintainability of their products to make them compatible with circular economy mindset. Using RFID's, QR codes and blockchain in conjunction with the IIoT could allow products to be readily identified (Amsler, 2022) and then assessed in terms of condition and service/repair requirements. By storing data on or in the product the best choice can be made when deciding to service or recycle, in the automotive sector the vehicles history and previous repairs could be digitised and stored online. For the automotive sector this could help keep vehicles on the road for longer as the additional data could assist diagnostics for repairs and in turn could vehicles being written off and going to landfill. If cars also become more modular, then products from one vehicle can be applied to another reducing complexity of supply and service chains and reducing overall waste.

Design for circularity,

Industry 4.0 methodologies can become a cornerstone in designing and producing parts for the circular economy. By utilising the Internet of Things, the sustainability of vehicles can be enhanced. Sourcing spare or repair components may become easier with more connected service and manufacturing teams. Materials can also be sourced with greater knowledge of their origin if Big Data can be incorporated into supply chains (Columbus, 2015). Non-safety critical components could also be additively manufactured to keep vehicles running for longer even when the components have stopped being produced en-masse.

A different sales approach to the automotive sector can also transform how business models work for both OEMs and users. The traditional current model is for consumers to purchase or lease a vehicle, to be used for a number of years and then sold or returned. With autonomous vehicles likely to become to norm in future, vehicle ownership may become a thing of the past, instead, people will use apps such as uber to hail autonomous vehicles as and when they are needed as seen in similar such services today, for example ZipCar (Beiker, 2013). This will reduce the overall quantity of vehicles required, as cars will be used around the clock rather than being stationary and parked for the majority of their lifespan, as (Milta, 2017) shows cars spend up to 95% of their time parked. A reduction in the overall quantity of vehicles in a given area results in an overall reduction in materials used, further aiding moves towards sustainability the circular economy. All of which is enabled by i4.0 technologies in both the apps, The Cloud, IoT and the smart sensors systems in autonomous ADAS level 5 vehicles (Schroer, 2022).

Design for Serviceability.

A new approach to vehicles can also extend their lifespan through refurbishment, the Toyota approach shown by (Seto, 2022), can be seen a step towards a more sustainable car sector. Once the vehicle has gone through several refurbish cycles, they also plan to recycle the parts that can still be used. Combining this with greater modularity between platforms can also reduce the variety of components required to keep cars going for longer and reducing costs and waste. Strict end of life legalisation (ITS International, 2012), may see more OEMs move towards this type of scheme.

Industry 4.0 can also play a big part for electric vehicles, already apps are used to identify the location and waiting times of charging stations (Dolan, 2022). OEM Nio also offers a novel approach

by swapping the battery entirely. Users can approach the station and with the aid of an app and the vehicle autonomously navigating itself into the docking station, the battery is then replaced in around 3 minutes for a charged one (Nio, 2023). With Battery degradation (Zheng, et al., 2015) being a key obstacle in the long-term sustainability of Electric vehicles, the ability to swap them out readily could be significant.

Repurposing car batteries could also be an option for extending their life until they are recycled. One option is to install the batteries into homes (Martin, 2022) so that energy can be stored from renewable sources such as solar panels and also help houses through blackouts.

Using RFIDs, QR codes, Blockchain, The Cloud and the IoT can also improve the data that any given product can carry. For the example of cars, the condition of the vehicle and its components can be updated at servicing or even live to ensure that parts are adequately replaced or serviced where applicable (Kalverkamp & Raabe, 2018). This can aid in recycling by providing information to those decommissioning a vehicle with optimal and up to date data.

Summary and Conclusion

Industry 4.0 can offer to revolutions almost every aspect and the product cycle. These advancements start from product design and the use of AI and the Cloud for generative design, simulation and testing.

Batch production and additive manufacturing will play increasing roles in both prototype part production but also customisation for serial products. Smart factories will become more agile in terms of manufacturing requirements in order to meet these new demands. Products will also be produced with serviceability and the circular economy in mind for improved sustainability.

During product use the increased connectivity via the IIoT and the Cloud will revolutionise how existing products are used and create entirely new business models.

At the 'end of life', products can be repaired and serviced more ably to extend their use. Smart identification technologies (QR codes, RFIDS etc) connected to the internet can be used to ensure that the optimal number of parts can be re-used, recycled or re-purposed.

For the automotive industry, the very business models that have supported the industry are set to radically change. This will be partly due technological advancements and autonomous driving becoming the norm but also due to government legislation that will require design tailored towards the circular economy. Strict recycling laws will push OEMs into favouring refurbishment and modularity of vehicles to extend their lifespan.

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