Unlock the Potential of Open AI in Smart Manufacturing

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1.1 PURPOSE

The key purpose of this article is to help the reader understand the current landscape of Generative AI and potential application of Open AI LLMs (large language models) including ChatGPT for industry priority scenarios in smart manufacturing. The article covers the application of Open AI models (a Generative AI technology) primarily focusing on aiding product design using code and content generation, process automation using smart assistants or copilots and industrial knowledge management for IOT scenarios.

1.2 EXECUTIVE SUMMARY

Smart manufacturing is the use of advanced technologies and data to optimize the production process, improve product quality, reduce costs, and enhance sustainability. One of the technologies that is transforming the manufacturing industry is Generative AI, which is a type of AI that can create new content and ideas, such as designs, images, videos, music, and text. These systems fall under the broad category of machine learning and are often known as large language models (LLMs), a class of *foundation models*. It can be used to solve various challenges in the manufacturing and industrial sectors, such as[1]:

- Product development and design: Generative AI can explore various design options within specified parameters, such as materials, constraints, safety factors, and cost. This can enable faster and more efficient innovation, as well as more customized and personalized products.
- Customer service automation: Generative AI can generate natural language responses to customer queries, complaints, or feedback. This can improve customer satisfaction, loyalty, and retention.
- Manufacturing (production) optimization: Generative AI can analyze production data and identify patterns, anomalies, bottlenecks, and opportunities for improvement. This can enhance operational efficiency, quality control, waste reduction, and resource utilization.
- Supply chain management: Generative AI can forecast demand and supply, optimize inventory levels, plan logistics and transportation routes, and mitigate risks. This can increase the agility, resilience, and profitability of the supply chain.
- Machine-generated events monitoring: Generative AI can interpret telemetry from equipment and machines to predict and prevent failures, recommend solutions, and

[1] *https://cloud.google.com/blog/topics/manufacturing/five-generative-ai-use-cases-for-manufacturing* and *https://venturebeat.com/ai/ai-is-making-smart-manufacturing-faster-greener-virtual-and-more-real/*

optimize maintenance workflows. This can reduce downtime, increase productivity, and lower maintenance costs.

However, Generative AI also requires careful implementation and management to ensure its reliability, security, and ethics. Manufacturers need to adopt a data-centric approach to ensure the quality and availability of data for generative AI models. They also need to establish clear standards and guidelines to ensure the safety and accountability of generative AI applications. By doing so, manufacturers can leverage the full potential of generative AI for smart manufacturing.

2 INTRODUCTION

Smart manufacturing refers to the use of advanced technologies and data to optimize the production process and create more value for customers and stakeholders. To unlock the full potential of Smart manufacturing in the Industry 4.0 era, Generative AI, is set to accelerate the transformation.

Generative AI is a type of AI that creates content and ideas, such as conversations, stories, images, videos, and music from simple prompts and context. These systems fall under the broad category of machine learning and are often known as large language models (LLMs), a class of *foundation models*.

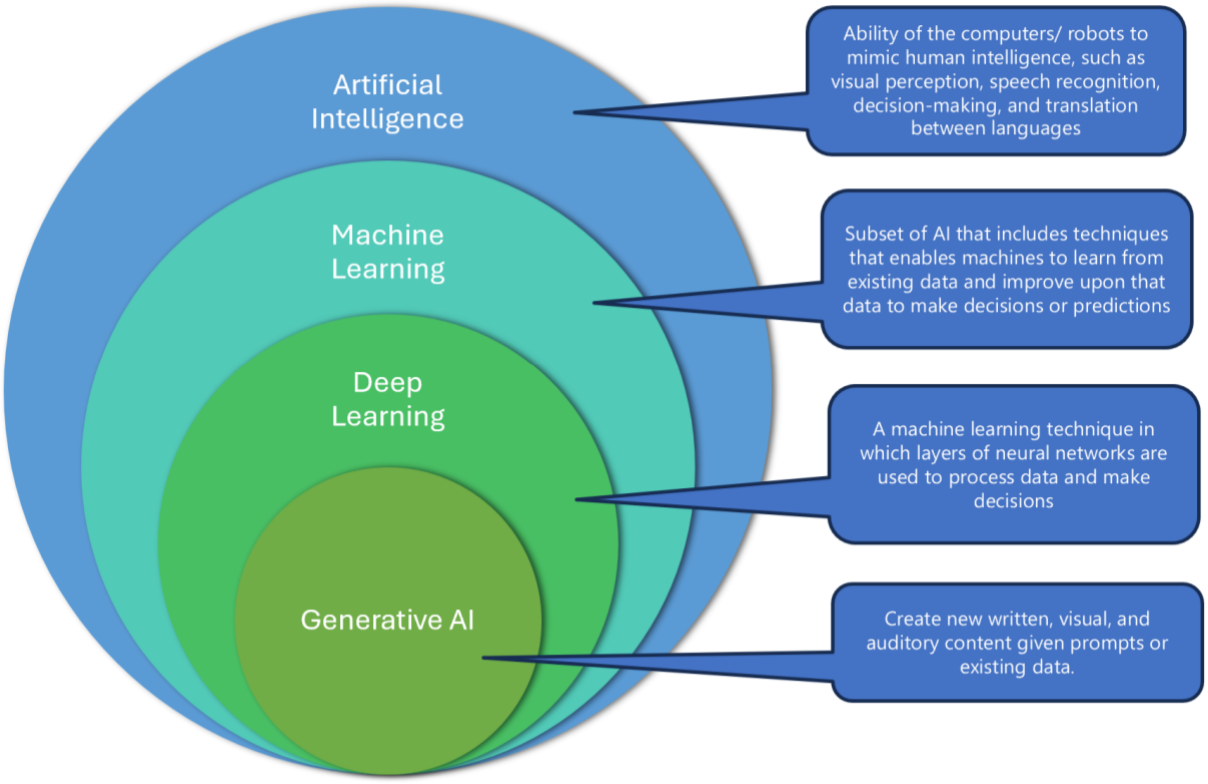

Figure 2-1: The Generative AI Evolution.

Transformers were a generative AI breakthrough:

A transformer model is a type of neural network that learns context and meaning by tracking relationships in sequential data, such as words in sentences, pixels in images, or notes in music.

They are scalable, which means their performance and accuracy improve as they are made larger and fed more data. But more importantly, transformer models can be trained through self-supervised or unsupervised learning, meaning they require no or very little human-annotated data.

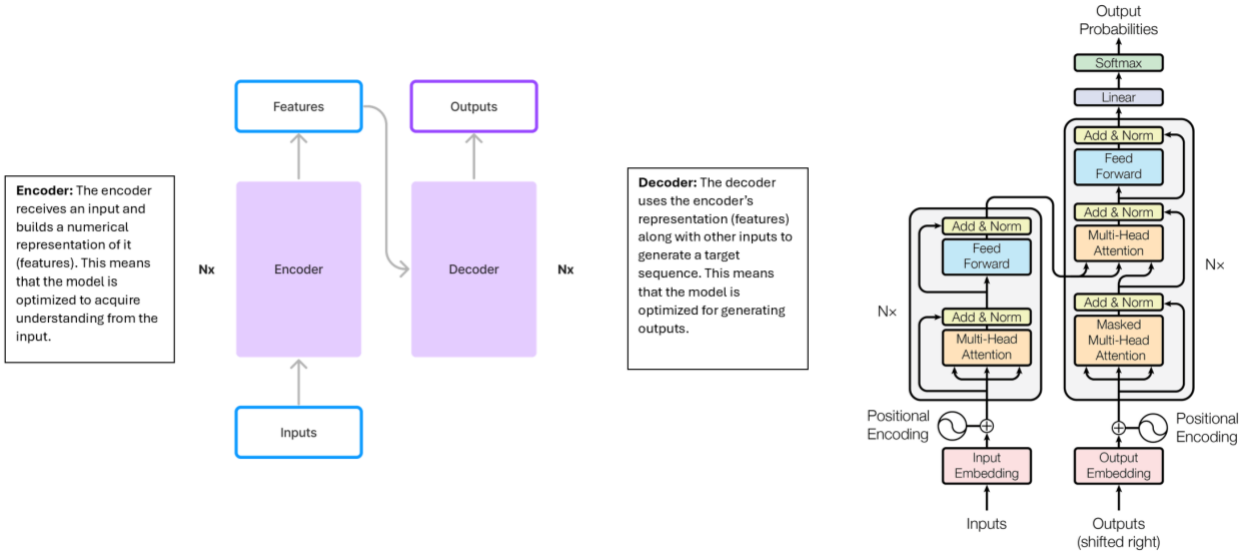

Figure 2-2: Transformer architecture[2].

Transformers can detect trends and anomalies to prevent fraud, streamline manufacturing, make online recommendations, generate initial code drafts, code correction and refactoring, root-cause analysis, and generate new system designs.

People use transformers every time they search on Google or Microsoft Bing. OpenAI advanced the transformer approach with GPT-2 and GPT-3 (GPT - Generative Pretrained Transformer).

2.1 The Generative AI Foundation Model

A foundation model is a machine learning model that is trained on a large amount of unlabeled data, allowing it to be adapted to a wide variety of tasks. These models capture general patterns and structure of data, and aim to replace task-specific models by unifying different tasks and modalities into one, eliminating the need to train individual models and integrate several models together. An example is a large language foundation model that can perform various NLP tasks and can be used out-of-the-box due to its extensive training.

[2] *https://machinelearningmastery.com/the-transformer-model/*

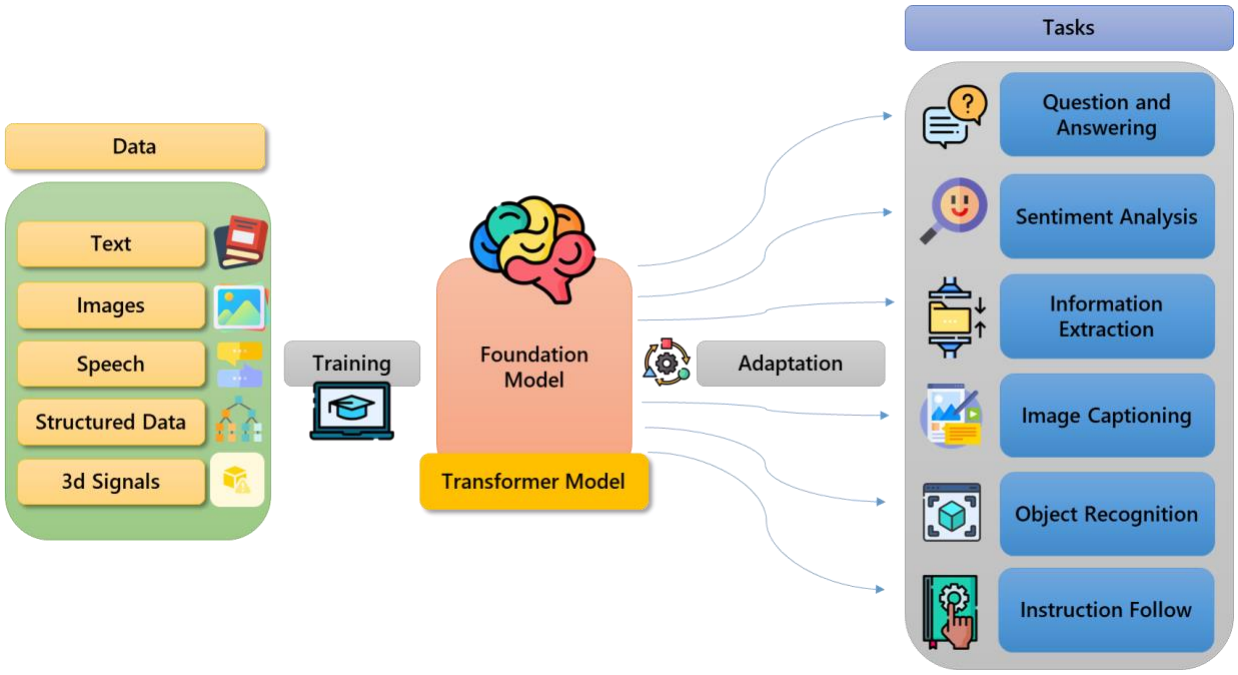

Figure 2-3: Foundation model[3].

3 MOTIVATION

Generative AI has the potential to accelerate transformation in manufacturing by:

- Enabling innovation, efficiency, and optimization in various aspects of the industry. This will enable industries, including manufacturing, automotive, aerospace and defense, to design parts that are optimized to meet specific goals such as performance, materials, and manufacturing methods.
- Training in large datasets of historical data, generative AI algorithms can produce new and innovative designs while considering a wide range of constraints such as cost, safety, and performance. This can help manufacturers reduce product development time, optimize production lines, and improve product quality.
- Embracing new design and manufacturing paradigms and preparing for the future with the new Industrial Metaverse. Manufacturers will increasingly include industrial metaverse technologies in their digital transformation roadmap to address advanced simulation, cross-domain collaboration, and safety.
- Running product lifecycle management applications (PLM) and computer-aided design workloads on the cloud to gain agility, efficiency, and scalability.

[3] *https://blogs.nvidia.com/blog/what-is-a-transformer-model/*

- Enabling In discrete manufacturing, where automotive manufacturers are using generative AI to design lightweight, high-strength components that can withstand the rigors of high-speed driving.

Empowering consumer goods manufacturers in deploying generative AI to improve product design, production, and supply chain management.

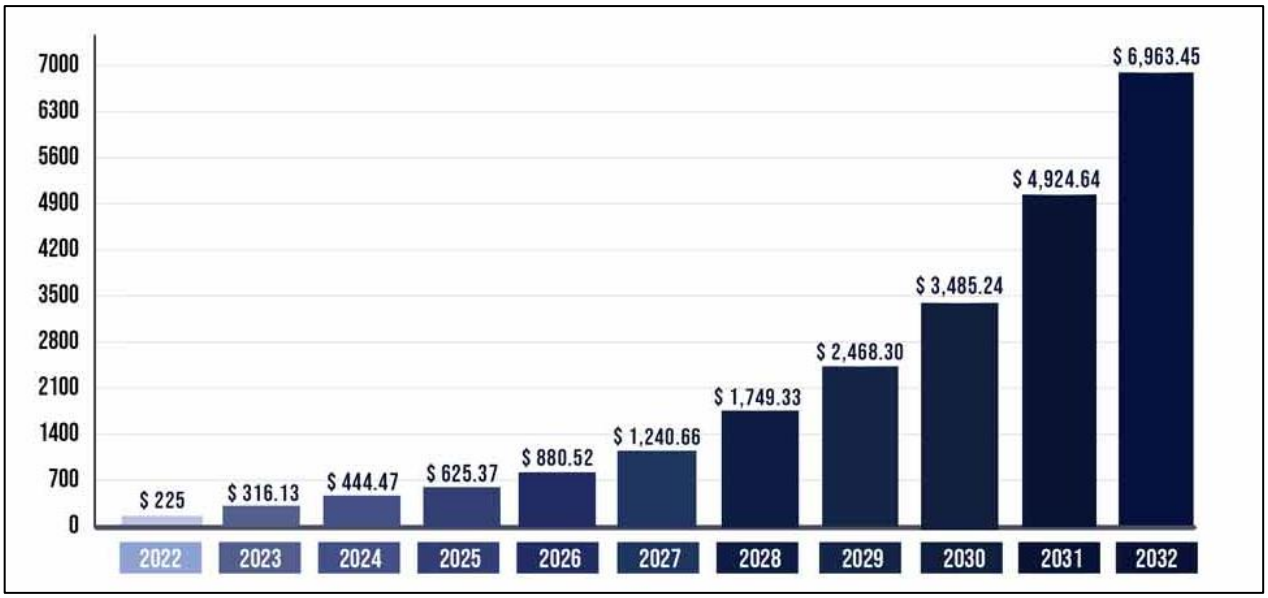

Figure 3-1: Generative AI in the manufacturing market size, 2022-2032 (USD million)[4].

Generative AI technologies can be leveraged for IOT and other digital applications for industrial knowledge management, aiding product design leveraging code and content generation, Process automation using copilots to stay innovative and meet evolving customer demands which is essential for business success and revenue growth.

Figure 3-2: Key use cases for smart manufacturing.

3.1 Manufacturing Knowledge Management

Manufacturing enterprises frequently create and maintain knowledge base about business processes, customers, products, and information. However, retrieving relevant content based on

[4] *https://www.precedenceresearch.com/generative-ai-in-manufacturing-market*

a user query over a large and diverse set of enterprise data sources data is often challenging. The user can query the knowledge base and find an applicable document by using methods like page rank, but extracting information from the unstructured documents to search for relevant information typically becomes a manual task that takes time.

With the recent advancement in foundation transformer models - OpenAI GPT models (Generative AI models developed by Open AI organization), the query mechanism has been refined by semantic search methods that use encoding information like embeddings to find relevant information. These developments enable the ability to summarize content and present it to the user in a concise and succinct way.

The architecture uses a Cognitive Search engine to rank the retrieved documents in order of relevance, and then uses the Open AI GPT-3 completions endpoint with the summarizer to generate a summary of the extracted content.

For example, the user can enter a query like “How does the new product compare to the existing products in terms of performance and cost?” and get a summary of the document that compares the new product with the existing products.

Below is a conceptual architecture of the manufacturing knowledge management which can be leveraged in Smart Manufacturing for several scenarios like:

- Intelligent remediation/ troubleshooting assistance to field engineers
- Equipment Training guide/ Safety document summarization
- Internal Safety Bot always on response to safety issues and
- Intelligent enterprise search scenarios

3.2 CONCEPTUAL ARCHITECTURE

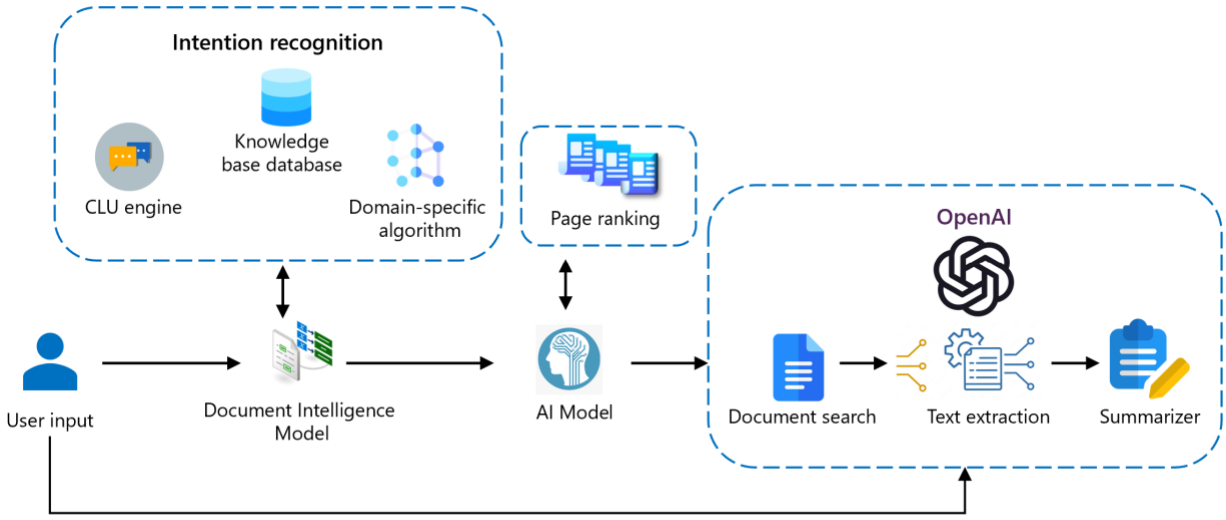

Figure 3-3: AI-driven knowledge management and intelligent search[5].

The above workflow occurs in the near-real time where a user sends a query to the enterprise knowledge vault.

For example, an employee of a manufacturing company is searching for specific information about a machine part on the company portal.

The query is first processed by an intent recognizer like conversational language understanding. The relevant entities or concepts in the user query are used to select and present a subset of documents from a knowledge base that's populated offline (in this case, the company's knowledge base database).

The output is fed into a search and analysis engine like Cognitive Search, which filters the relevant documents to return a document set of hundreds instead of thousands or tens of thousands.

The user query is applied again on a search endpoint to the Intelligent Cognitive Search engine to rank the retrieved document set in order of relevance (page ranking). The highest-ranked document is selected. The selected document is scanned for relevant sentences. This scanning process uses either a coarse method, like extracting all sentences that contain the user query, or a more sophisticated method, like GPT-3 embeddings, to find semantically similar material in the document.

[5] *https://learn.microsoft.com/en-us/azure/ai-services/language-service/summarization/how-to/document-summarization*

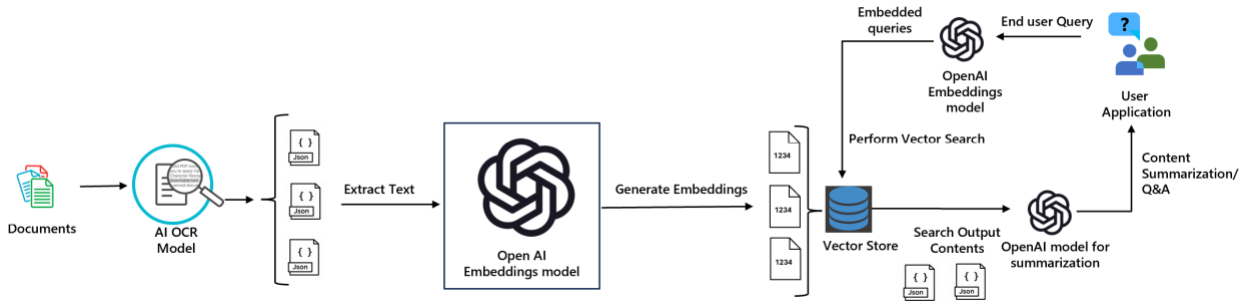

Figure 3-4: Open AI model in an enterprise knowledge search/mining scenario[6].

After the relevant text is extracted, the GPT-3 Completions endpoint with the summarizer summarizes the extracted content. In this example, the summary of important details about the part that the employee specified in the query is returned.

Document summarization is the process of creating summaries from large volumes of data while maintaining significant informational elements and content value. The above architecture demonstrates how to use OpenAI Service GPT-3 natural language processing capabilities for a range of tasks, including language translation, chatbots, text summarization, and content creation. The above architecture is customizable and can be applied to many datasets.

Here is a sample code to use OpenAI Document summarization API for the manufacturing industry. The pre-requisite for this code is to install the OpenAI Python package and set the API key as an environment variable. The code takes a document and a query as inputs and returns a summary that answers the query.

```
import openai

# Define the document and the query

document = "Manufacturing is the production of goods through the use of
labor, machines, tools, and chemical or biological processing.
Manufacturing is a major source of economic activity and employment in
many countries. Manufacturing can be classified into different types,
such as discrete manufacturing, process manufacturing, lean
manufacturing, agile manufacturing, and mass customization. Discrete
manufacturing involves the production of distinct items, such as cars,
furniture, or toys. Process manufacturing involves the production of
goods that are usually produced in bulk quantities, such as oil, gas,
chemicals, or food. Lean manufacturing is a set of principles and
practices that aim to reduce waste and improve efficiency and quality
in the production process. Agile manufacturing is a set of strategies
and methods that enable a company to respond quickly and flexibly to
changing customer demands and market conditions. Mass customization is
```

[6] *https://github.com/samelhousseini/km-openai*

```
a form of production that combines the efficiency of mass production
with the variety and personalization of custom-made products."
```

query = "What are the benefits of mass customization in manufacturing?"

 # Define the prompt for the model

prompt = f"Document: {document}\nQuery: {query}\nSummary:"

 # Generate a summary using the OpenAI API

```
response = openai.Completion.create(
    engine="davinci",
    prompt=prompt,
    max_tokens=50,
    temperature=0.3,
    stop="\n"
)
```

 # Print the summary

```
summary = response["choices"][0]["text"]
print(summary)
```

The output of this code is:

Summary: Mass customization in manufacturing offers several benefits, such as increasing customer satisfaction, loyalty, and retention; enhancing product differentiation and competitive advantage; reducing inventory costs and risks; and improving operational efficiency and flexibility.

3.3 Code and Image Generation for Accelerating Product Design

OpenAI code generation capability for product design can be used in manufacturing industry in various ways.

1. **OpenAI Codex** is a natural language-to-code system based on GPT-3, that helps developers create and debug code for factory automation, product simulation, and data analysis. For example, GitHub Copilot is powered by a generative AI model that helps developers or designers to write code faster and thus improves the productivity of the process. It draws context from comments and code to suggest individual lines and whole functions instantly.

Figure 3-5: GitHub Copilot[7].

Here are the sample code and examples on how GitHub Copilot can create and debug code for factory automation and product simulation. The code is written in Python and uses the pandas library for data manipulation.

Example: Factory Automation

```
# Define a function to calculate the total production cost of a batch of products

# Input: a pandas DataFrame with columns 'quantity', 'unit_cost', and 'overhead'

# Output: a float representing the total cost

def calculate_total_cost(df):

# Multiply the quantity and unit cost of each row to get the subtotal
```

[7] *GitHub Copilot for VS Code - DEV Community*

```
df['subtotal'] = df['quantity'] * df['unit_cost']

    # Sum the subtotal and overhead columns to get the total cost

    return df['subtotal'].sum() + df['overhead'].sum()

    # Example

    import pandas as pd

    # Create a sample DataFrame with some data

    df = pd.DataFrame({'quantity': [10, 20, 15, 25], 'unit_cost': [5, 4,
    6, 7], 'overhead': [100, 150, 200, 250]})

    # Call the function to calculate the total cost

    total_cost = calculate_total_cost(df)

    # Print the result

    print(f'The total production cost is ${total_cost:.2f}')

    # Output

    The total production cost is $1050.00
```

Example: Product Simulation

```
    # Define a function to simulate the performance of a product under different scenarios

    # Input: a pandas DataFrame with columns 'scenario', 'demand', 'price', and 'cost'

    # Output: a pandas DataFrame with columns 'scenario', 'revenue', 'profit', and 'profit_margin'

    def simulate_performance(df):

    # Calculate the revenue for each scenario by multiplying the demand and price

    df['revenue'] = df['demand'] * df['price']

    # Calculate the profit for each scenario by subtracting the cost from the revenue

    df['profit'] = df['revenue'] - df['cost']
```

```
# Calculate the profit margin for each scenario by dividing the profit by the revenue

df['profit_margin'] = df['profit'] / df['revenue']

# Return the DataFrame with the new columns

  return df

# Example

import pandas as pd

# Create a sample DataFrame with some data

df = pd.DataFrame({'scenario': ['A', 'B', 'C', 'D'], 'demand': [1000,
800, 1200, 1500], 'price': [10, 12, 8, 9], 'cost': [5000, 6000, 4000,
4500]})

# Call the function to simulate the performance

df = simulate_performance(df)

# Print the result

print(df)

# Output

scenario  demand  price  cost  revenue     profit  profit_margin

0        A    1000     10  5000    10000    5000       0.500000

1        B     800     12  6000     9600    3600       0.375000

2        C    1200      8  4000     9600    5600       0.583333

3        D    1500      9  4500    13500    9000       0.666667
```

2. **OpenAI ChatGPT** is a natural *language-to-code* chatbot which is based on GPT-3. This can be used to assist product designers in creating and modifying design elements using natural language commands.

   ChatGPT can interact with design tools like Figma to generate code for different platforms from the design elements[8]. For example, a product designer can ask ChatGPT to create a button with a specific color and size, and ChatGPT will generate the code for that button in HTML, CSS, or React.

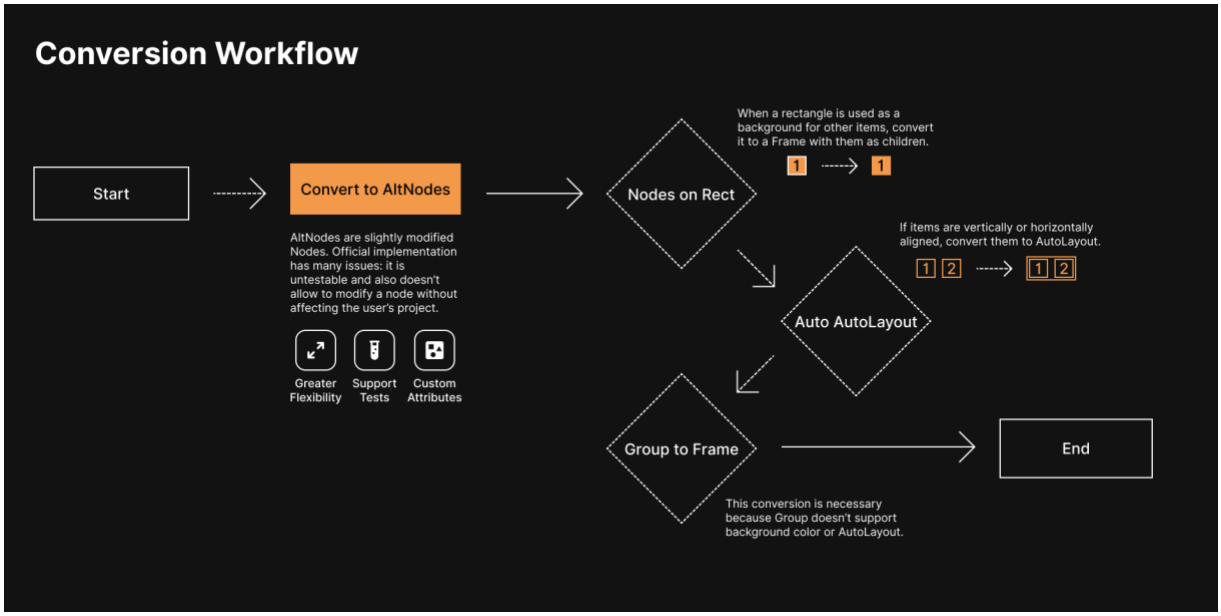

Figure 3-6: Figma leverage Generative AI for code generation[9].

3. **OpenAI DALL-E** is a generative image model based on GPT-3 that helps product designers explore new ideas and concepts for product design. DALL-E can generate realistic images from text descriptions, allowing product designers to visualize their ideas and get inspiration.

The image in Figure 3-7 is generated using DALL-E model by converting this text to image: "Design a cooling machine for manufacturing industry."

[8]*https://bootcamp.uxdesign.cc/supercharging-design-workflows-empowering-product-design-teams-with-chatgpt-ce678961d44d*

[9]*https://www.producthunt.com/posts/figma-to-code*

Figure 3-7: DALL-E for image generation from text for product design.
Generated using Azure Open AI Studio.

For example, a product designer can ask DALL-E to generate an image of a futuristic car with solar panels and wings, and DALL-E will produce an image of such a car. Mattel has been using DALLE to spark creativity across the entire organization from toy design to marketing.

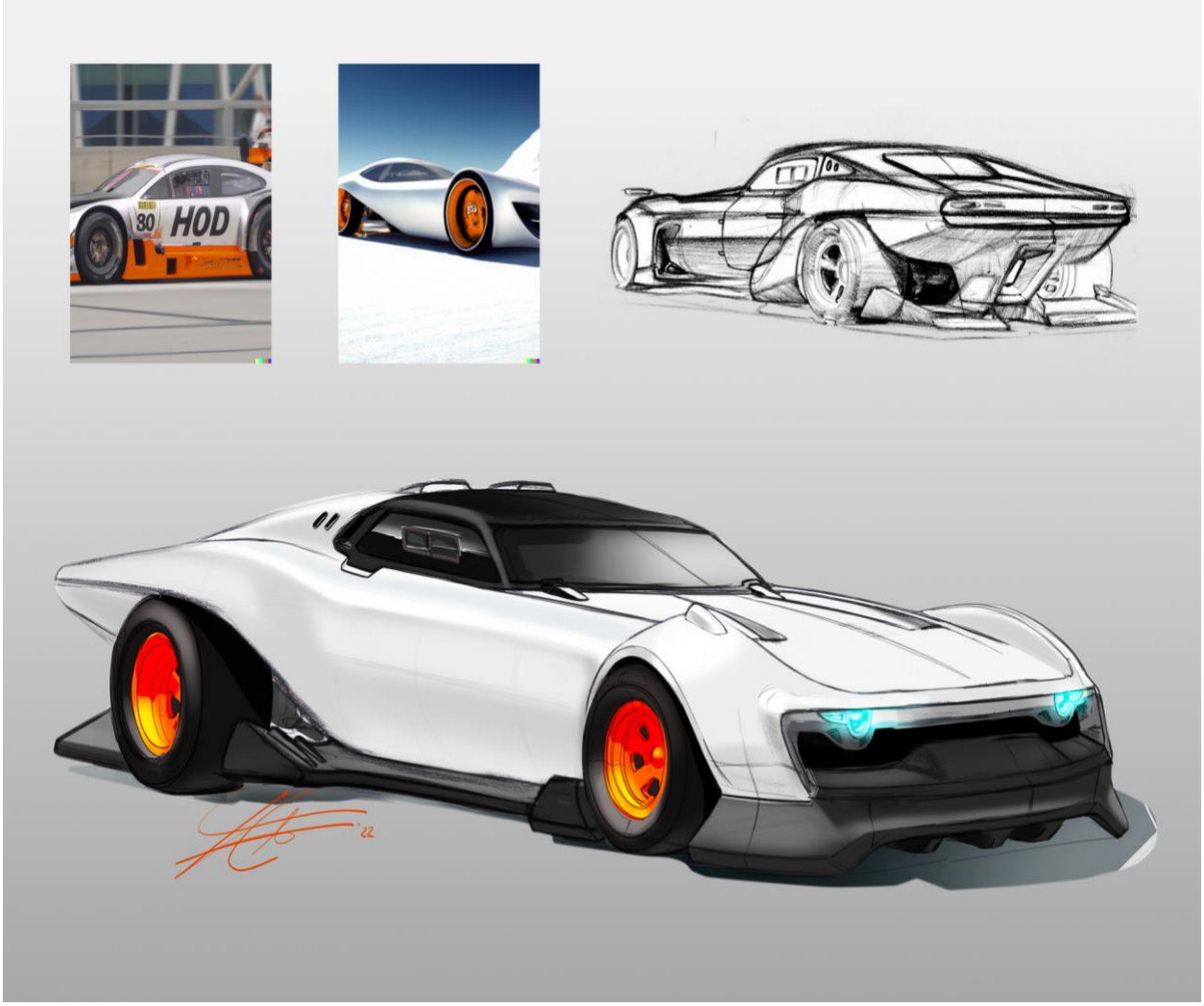

Figure 3-8: Generations from Mattel using DALL-E 2[10].

4. Copilot for Smart Manufacturing

OpenAI for Manufacturing Copilot framework aims to use generative AI models to assist manufacturing engineers and operators in various tasks such as designing, optimizing, troubleshooting, and maintaining production systems.

The framework is based on the natural language as the interface between humans and machines, and leveraging the power of OpenAI Codex, that can understand and generate natural language and code.

[10] *https://news.microsoft.com/source/features/ai/from-hot-wheels-to-handling-content-how-brands-are-using-microsoft-ai-to-be-more-productive-and-imaginative/*

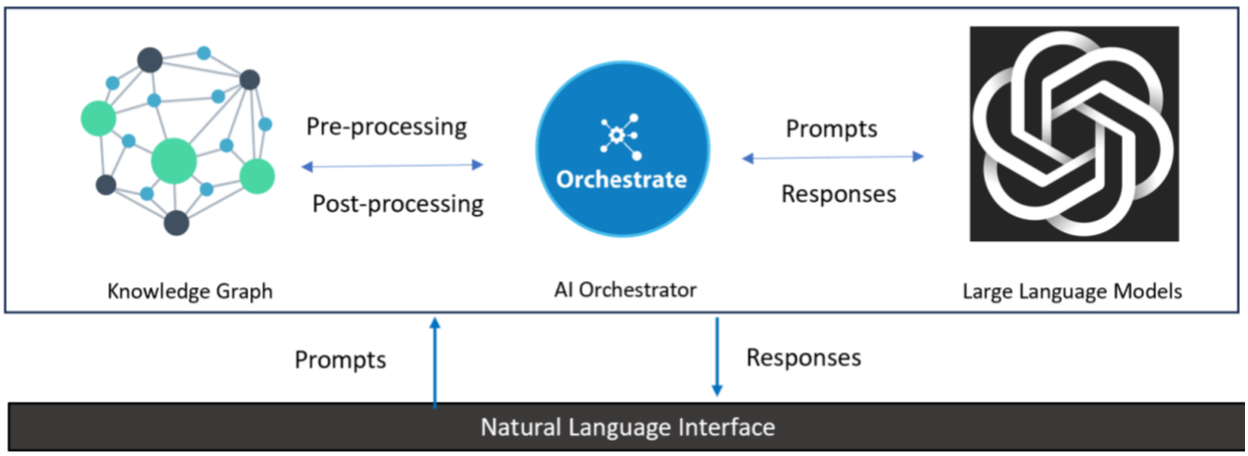

Figure 3-9: Copilot conceptual diagram[11].

The framework consists of the key components below:

- The **Natural Language Interface** allows users to express their intents and queries in plain English and receive responses and suggestions from the AI system.
- **Large Language Models:**
    - A code generation engine that uses OpenAI Codex model to generate code snippets or scripts based on the user's natural language input and execute them on the target platform or device.
    - A data engine that uses OpenAI Codex (LLM) model to perform data processing, visualization, and reasoning over various data sources such as sensors, logs, databases, etc.
- A **knowledge graph** that stores and retrieves relevant information and best practices for manufacturing processes, systems, and products.
- The **AI Orchestrator,** which co-ordinates with all other components to execute the complete flow.

For an input natural language question, it first calls into *Embeddings* and *Similarity* models[12] to understand the keywords in the question. Based on those it can decide the information retrieval systems it should use – example if it a simple facts-based question it can search the answer in an index and/or it can use the embeddings to filter the contextualized request-response pairs and perform prompt engineering[13] for the LLM.

[11] *https://learn.microsoft.com/en-us/microsoft-365-copilot/microsoft-365-copilot-overview*
[12] *https://openai.com/blog/introducing-text-and-code-embeddings*
[13] *https://www.promptingguide.ai/techniques*

Then, the input question along with the prompt is sent to the LLM to retrieve an answer, which it then executes on the data services which is a Graph database. It then finally creates a response to the input question.

The framework can be integrated with various manufacturing platforms and devices, such as PLCs, CNCs, robots, IoT sensors, etc., and can support various programming languages and frameworks, such as Python, C#, Java, etc.

The framework can enable various use cases and benefits for manufacturing, such as:

- Improving the efficiency and quality of design and development by providing code suggestions, templates, and examples based on the user's specifications and requirements.
- Enhancing the performance and reliability of production systems by providing optimization tips, troubleshooting guides, and maintenance schedules based on the data analysis and knowledge base.
- Reducing the cost and time of training and upskilling by providing interactive tutorials, quizzes, and feedback based on the user's level of expertise and learning goals.
- Increasing the innovation and creativity of manufacturing solutions by providing inspiration, brainstorming, and prototyping tools based on the user's ideas and challenges.

Similar solutions have been developed or proposed by other researchers and companies, such as:

- ***GitHub Copilot***[14], a service that provides access to large-scale generative AI models that can understand and generate natural language and code. It can help developers with writing assistance, code generation, and reasoning over data.
- ***Azure OpenAI Copilot***[15], a service that provides access to large-scale generative AI models that can understand and generate natural language and code. It can help startups with building, managing, and deploying AI solutions using various tools and services.

4 INDUSTRY APPLICATIONS & SUCCESS STORIES IN SMART MANUFACTURING

- **Product engineering:** Generative AI can help product designers create innovative new designs within parameters specified by the user, such as materials, manufacturing constraints, safety factors, and other variables.

[14] *https://github.com/features/copilot*

[15] *https://startups.microsoft.com/blog/8-steps-to-building-an-azure-openai-copilot-for-your-startup/*

    - **Case Study:** Autodesk offers generative design capabilities in their Fusion 360 software to help product designers explore various design options and find the most efficient solutions[16].

- **Production optimization:** Generative AI can help optimize production processes by learning from data and generating optimal solutions for scheduling, planning, routing, quality control, and maintenance.
    - **Case Study:** Siemens uses generative AI to optimize the production of gas turbines by generating optimal configurations of blades and cooling channels[17].
- **Supply chain management:** Generative AI can help improve supply chain logistics by generating optimal plans for inventory management, demand forecasting, transportation, and distribution.
    - **Case Study:** Amazon uses generative AI to optimize its delivery network by generating optimal routes and schedules for its drivers and drones[18].
- **Customer Experience:** Content Generation and Summarization capabilities of Open AI are leveraged by several manufacturers and retailers to improve customer experience.
    - **Case Study:** A renowned US based retailer car company leveraged OpenAI's API and Azure OpenAI Service's content generation feature to generate customer-relevant content for its website, specifically, AI-generated car review summaries.

The goal was to create summaries for 5,000 car pages—a task that, if done manually, was estimated to take approximately 11 years[19].

5 GUIDING PRINCIPLES OF RESPONSIBLE GENERATIVE AI STRATEGY IN MANUFACTURING

Successfully infusing Generative AI into the Smart manufacturing processes requires business leaders to practice big-picture thinking that considers not just what Generative AI can do, but what it should do. Generative AI also poses some challenges and risks, such as ethical, legal, and social implications, data quality and security, model explain-ability and trustworthiness, and human-machine collaboration. Therefore, it is important to adopt a responsible Generative AI strategy in manufacturing that follows some guiding principles.

[16] *https://www.autodesk.com/solutions/generative-design*

[17] *https://www.siemens.com/us/en/company/press/press-releases/digital-industries/siemens-microsoft-generative-artificial-intelligence.html*

[18] *https://aws.amazon.com/blogs/industries/generative-ai-in-manufacturing/*

[19] *https://news.microsoft.com/source/features/ai/azure-openai-service-helps-customers-accelerate-innovation-with-large-ai-models-microsoft-expands-availability/*

Below are the few guiding principles and perspectives on responsible Generative AI strategy[20].

- Responsibility: Generative AI should be designed and used in a way that respects human dignity, rights, values, and norms. It should also be fair, transparent, explainable, and inclusive, avoiding or mitigating any potential biases or harms to individuals or groups.
- Principles: Develop principles that reflect the organization's values, intent, and approach to product innovation, in the supply chain, and in production.
- Practices: Adopt practices and tools to apply throughout the manufacturing lifecycle. Generative AI is a rapidly evolving technology that requires continuous learning and improvement. Therefore, it is important to adopt an agile and iterative approach to Generative AI implementation, starting with small-scale pilots and experiments to test the value proposition and feasibility of use cases, then scaling up the successful ones across the organization or ecosystem[21].
- Tools: Implement best practices around Generative AI system development lifecycle by infusing error analysis, interpretability of machine learning models and bias mitigation.
- Governance: Determine and establish a strong governance and compliance framework that builds trust and confidence among all stakeholders. Generative AI comes with risks, among them IP and copyright infringement, cybersecurity breaches, data privacy violations, and unintended consequences. Therefore, it is necessary to have clear and consistent policies and standards for data collection, storage, sharing, and usage; model development, testing, deployment, and monitoring; and accountability and liability.

6 CONCLUSION

Open AI can support the development and adoption of Industry 4.0 and smart manufacturing solutions by providing open-source platforms, frameworks, and tools for AI and machine learning applications. Industry 4.0 and digital factory can benefit from Open AI by ensuring that their technologies are ethical, trustworthy, and accountable. The possibilities are endless. Generative AI/ OpenAI can potentially add value to:

- Convert unstructured NLP feeds into structured data points.
- Allow designers to generate product design based on consumer sentiment and feedback.
- Optimize material usage/requirements in the design process.

The potential outcomes of leveraging Open AI are multi-fold:

[20] *https://news.microsoft.com/futurecomputed/*

[21] *https://www.gartner.com/en/doc/797407-use-case-prism-generative-ai-for-manufacturing*

- Shorten the time to market by updating features of digitally connected products through the cloud resulting in improvement in ROI.
- Improve customer experience by applying digital transformation on traditional product innovation processes and increase revenue generation.
- Prevent bottlenecks and production challenges through Improvement and validation of designs by production engineers.

Improve operational efficiencies and cost by providing on-time knowledge feed to Field engineers, mitigating the risk of device failures in a manufacturing unit.

APPENDIX A GENERATIVE AI MARKET LEADERS – AN INDUSTRY OVERVIEW

Big technological companies are investing heavily in Generative AI:

Microsoft

- In January 2023, Microsoft announced the third phase of a long-term partnership with OpenAI through a multi-year, multibillion dollar investment to accelerate AI breakthroughs.
- Features of ChatGPT is eventually being built into all of Microsoft's products[22]. DALL-E already shows up in tools such as Microsoft Designer.
- GitHub Copilot, the company's generative code tool, has learned to translate between English and various programming languages.
- A new AI-powered Copilot for Microsoft 365 apps and services was announced in March 2023[23].

Google

- Google has been researching generative AI for years and has several LLMs including Language Model for Dialogue Applications (*LaMDA*[24]) along with models to generate code, speech, images, music, and video.
- In February 2023, the company announced Bard[25], its LLM-based conversational AI; several other generative AI announcements were made in March 2023[26].

[22] *https://www.microsoft.com/en-us/worklab/kevin-scott-on-5-ways-generative-ai-will-transform-work-in-2023*

[23] *https://www.theverge.com/2023/3/16/23642833/microsoft-365-ai-copilot-word-outlook-teams*

[24] *https://blog.google/technology/ai/lamda/*

[25] *https://blog.google/technology/ai/bard-google-ai-search-updates/*

[26] *https://blog.google/technology/ai/ai-developers-google-cloud-workspace/*

Amazon & Baidu

- AWS and Hugging Face have formed a partnership to make the training, fine-tuning, and deployment of large language and vision models more accessible to developers.
- China's Baidu is developing a chatbot similar to ChatGPT and plans to integrate the technology into its main search engine as soon as March 2023[27].

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