CAST

Constructive Approach to Smart Technologies

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Co-Leads:

- *Borys Stokalski*, RETHINK*
- *Bogumił Kamiński*, SGH Warsaw School of Economics*

The report was written by:

- Borys Stokalski*, RETHINK
- Daniel Kaszyński†, SGH Warsaw School of Economics
- Bogumił Kamiński*, SGH Warsaw School of Economics
- Ewelina Kędzior†, SGH Warsaw School of Economics
- Robert Kroplewski*, Kroplewski Law Office

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* Expert
(n.b. Robert Kroplewski is Expert in GPAI's Innovation & Commercialization and Data Governance Working Groups)
** Observer

† Invited Specialist

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I/ Introduction

> *"The development of AI is a journey into the unknown that never ends, as each step forward reveals new horizons in our understanding of intelligence."*
> *~ ChatGPT (OpenAI)*
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> *"AI will never be ethical. It is a tool, and like any tool, it is used for good and bad. There is no such thing as a good AI, only good and bad humans. We are not smart enough to make AI ethical. We are not smart enough to make AI moral … In the end, I believe that the only way to avoid an AI arms race is to have no AI at all. This will be the ultimate defense against AI."*
> *~ MT-NLG (Nvidia)*

In response to the expanding landscape of digital technologies and the growing complexity of AI-based software solutions, we propose a single framework for gathering the best practices related to the development of AI-based solutions. This endeavour is driven by global digitalisation and "AI-tisation", both horizontally (i.e., covering new industries) and vertically (i.e., infiltrating existing use cases).

Let us consider a case study of an autonomous intralogistic platform[1] vendor based in Poland: a manufacturer of robots that usually work in warehouses. This company stands as an illustration of the transformative power of intelligent technologies: starting as the producer of Autonomous Mobile Robots (AMR), the company has evolved into a vendor of digital AI-platform supporting the design, implementation, and management of autonomous intralogistic operations for manufacturing facilities and warehouses.

As the company, after the initial seed-phase of gaining recognition in Poland, expanded into foreign markets, the development of a robust framework for AI-engineering practices became paramount. The capabilities of digital technologies continued to evolve, and systems designed for the Polish market needed to be adapted to foreign requirements and environment. This particular vendor underwent this adoption relatively evenly: the CAST framework principles, combined with responsible software engineering practices, allowed to accommodate AMR products to the dynamic environment of modern factories, providing safe and reliable navigation while constantly improving the intelligence of the system.

For instance, supplementing LiDAR-based[2] navigation with semantic mapping based on 3D vision ended-up to facilitate new sales and allowing the vendor for more complex use cases and implementations. On the intralogistics process level, these smart solutions can customize their operations based on real-time data and contextual information, thereby enhancing efficiency and productivity predictably and transparently. This is where capabilities such as visualisation, simulation and optimisation become critical for complex processes.

The system's current architecture needs to accommodate different components and design styles, combining stringent, real-time-oriented design with complex rule processing, machine learning and big data patterns. It is not a simple task for product teams and constitutes a challenge for companies which must not take shortcuts when ethical issues and business responsibilities such as: workers' safety, the elevation of human work or process performance predictability are at stake.

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[1] Intralogistics (internal logistics) is the branch of logistics related to organising the flow of information and materials within a given company.

[2] Light Detection and Ranging (LiDAR) is a method used for the distance measurement thought usage of light.

Based on cases similar to the one described above, we have drafted a framework supporting the development of both human-centric and autonomous software systems based on AI capabilities. Drawing from the experience of software engineering practices, we seek to establish a set of guidelines and principles that can navigate the intricacies of developing and implementing AI-driven solutions.

Moreover, we see the need to offer insights beyond engineering to cover the "responsible design" spectrum fully. Responsible design practices are well established in industries such as aerospace or pharma. With the advent of AI-based autonomous systems that coexist with humans, manage complex infrastructures, or deliver critical insights for impactful human decisions, we must reconsider how we design and build these solutions.

We firmly believe that the engineering challenges posed by AI need to be addressed promptly, drawing inspiration from the existing best practices of software product engineering. Good engineering is a cornerstone of responsible design. However, the "responsibility" does not end here. The ultimate goal is to provide a framework for building safe, transparent, scalable, and ethical AI-based software systems that can thrive in the dynamic digital era.

II/ Reflection

Smart Solutions often amplify risks associated with the increasing complexity of IT systems and specific AI-related risk factors, such as explainability and cognitive bias in automated decision-making. The capability to build robust Smart Solutions utilising the most advanced AI techniques, delivering breakthrough cognitive performance, requires a balanced mix of modern scientific, engineering and governance practices.

Moreover, comprehending the impacts of AI on human labour, economics, and societal processes demands a perspective that reaches beyond AI as solely a scientific research field.

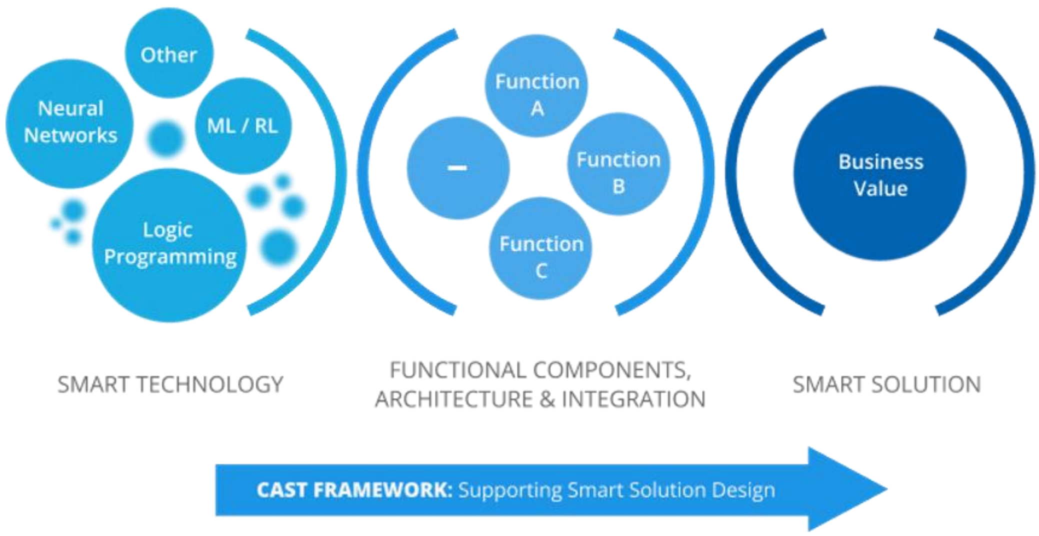


Figure 1. The Goal of CAST Framework to Assist Smart Solution Designers with Design Heuristics, Patterns and Use Cases
Source: Own elaboration

In the CAST framework, we identified and mapped several Smart Solution Patterns—repetitive combinations of tools, techniques, and system architecture components. To do so, we employ a **CAST "quadrant" framework**, with axes representing various dominant capabilities of Smart Solutions (see **Figure 4**).

This mapping provides insights for policymaking by rooting issues, objectives, results, and policies in specific categories of technology constructs rather than AI techniques, tools, or resources (such as data). These patterns represent principles utilised in engineering and design disciplines, serving as a codification of what currently constitutes best practice.

It is, therefore, crucial to grasp the fundamental differences between dimensions and the rationale behind employing two distinct axes to evaluate them. These dimensions, labelled as the "Modus Operandi dimension" and the "Motive dimension," offer unique perspectives on the nature of Smart Solutions.

1/ Modus Operandi - the first dimension

The “Modus Operandi dimension” focuses on the operational aspect, determining the level of autonomy exhibited by Smart Solutions. This dimension provides insights into whether these solutions act autonomously, to what extent, and under what circumstances human intervention may be required. It establishes a spectrum of behaviour, ranging from limited local autonomy to proactive autonomy, offering a comprehensive view of their operational capabilities.

The two extremes we see for this dimension are:

- Autonomy Oriented.
- Insight Oriented.

i/ Autonomy Oriented

In the context of Smart Solutions, the concept of autonomy plays a pivotal role in determining how these solutions operate and interact with their environment. Autonomy-oriented Smart Solutions can be categorised into different levels of independence, each with distinct characteristics.

At the fundamental level of autonomy, we encounter **Limited/Local Autonomy**. In this scenario, Smart Solutions possess autonomy closely tied to their local, immediate context. An illustrative example is a mobile robot that autonomously navigates its environment, avoids obstacles, and responds to the activities of other mobile agents in its immediate vicinity. However, the execution of a mission is typically assigned by a higher-level actor, which could be a human or another machine. In essence, Smart Solutions at this level can adapt to local conditions and perform tasks autonomously within a specific context.

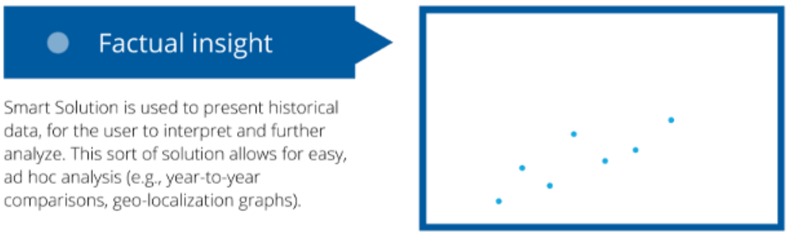
Execution Autonomy is at the second level of the autonomy hierarchy. Here, Smart Solutions no longer rely on guidance from the action recipient. Instead, goals and intents must be explicitly specified for these solutions to operate effectively. They can engage in "long" processes, making choices that lead to near-optimal scenarios and achieve predefined goals autonomously. However, this autonomy is contingent upon the context remaining within predefined tolerance parameters. Corrective action may be necessary if the context deviates beyond these parameters, typically requiring human intervention.

The highest level of autonomy within this dimension is **Pro-active Autonomy**. At this level, Smart Solutions exhibit a remarkable ability to accurately infer action goals and intent from the context in which they operate. They do not rely on explicit instructions but instead leverage data and contextual cues to make informed decisions and take appropriate actions. For instance, a care taking robot can provide assistance to patients based on their behaviour and health sensor data, effectively aiding them without the need for explicit directives. Pro-active autonomy represents high independence, where Smart Solutions can dynamically adapt and respond to changing circumstances of a complex nature with precision.

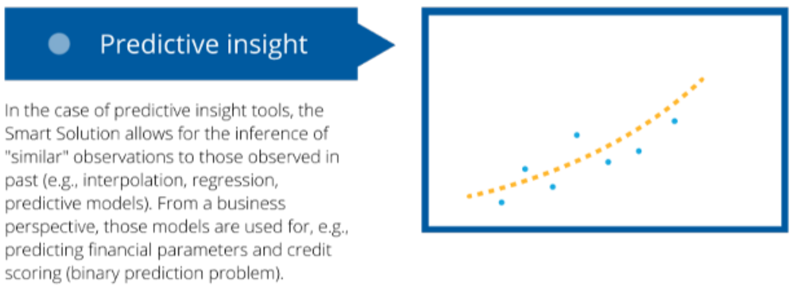
ii/ Insight Oriented

In the field of Smart Solutions, the Insight Oriented section holds paramount importance as it addresses the capacity of these solutions to deliver advanced insights that support recipients' actions, regardless if they are human or machine. This section introduces various levels of insight, each progressively more complex in its ability to provide valuable information.

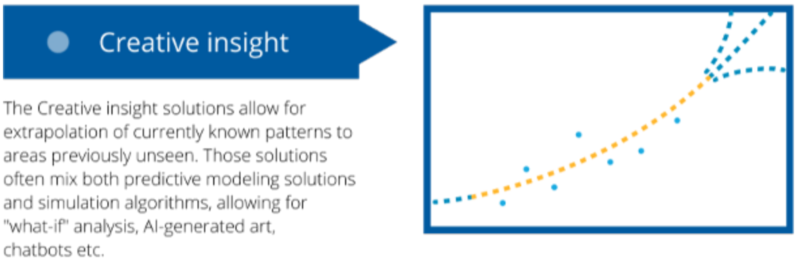
At the foundational level of insight, we encounter **Factual Insight**. In this scenario, Smart Solutions can collect and recognise relevant facts from data through advanced analytical processing. This capacity allows them to provide orientation based on a wealth of information. Factual insight is grounded in defined analytical models or heuristics, enabling Smart Solutions to derive valuable insights by processing observed data. These insights can be presented to recipients "on-demand" or as part of routine processes, either event-triggered or time-based.



As we analyse the hierarchy of insight, we reach the level of **Predictive/Adaptive Insights**. Smart Solutions operating at this level can apply heuristics and perform non-trivial extrapolations. This empowers them to infer actionable predictions from the data at hand. Moreover, these solutions can evaluate the adequacy of their existing models and heuristics, and they can propose or autonomously implement changes to enhance the quality of these models. This level of insight equips Smart Solutions with the ability to provide valuable information and anticipate future trends and outcomes.



Creative Insights is the peak of this dimension. At this level, Smart Solutions exhibits an extraordinary capability to generate new information and knowledge based on existing models and constraints. For instance, they can design a set of workspace layouts based on data such as spatial constraints, user preferences, or expectations related to the purpose of the workspace. What sets this level apart from the previous one is the ability of Smart Solutions to extrapolate beyond the data points seen in the training set. It engages in creative thinking and generates novel insights beyond conventional predictive and analytical approaches.



2/ Motive - the second dimension

The second dimension, defined as the "Motive Dimension", explores the underlying objectives and beneficiaries of Smart Solutions. It goes beyond operational aspects and examines the motives driving these solutions. This dimension distinguishes between Smart Solutions that enhance human capabilities or contribute to complex digital ecosystems. It helps us understand who or what benefits from deploying these solutions and the extent to which they align with specific user needs.

The two extremes or vectors we propose for this dimension are:

- Enhanced humans.
- Smart Digital Ecosystems.

i/ Enhanced humans

In the context of Smart Solutions, the Enhanced humans section is of particular significance, as it explores how machine actors can provide services that enhance human capabilities and deliver experience-oriented outcomes. This section outlines various levels of human capabilities enhancement, each catering to different aspects of improving the human experience.

Commodity Enhancement is at the fundamental level of human capabilities enhancement In this scenario, the machine actor provides services to enhance human capabilities without introducing significant changes. These services are typically straightforward and aim to address common needs. Examples of commodity enhancement may include solutions that improve mobility, understanding, perception, influence on the environment, specific skills, or deliver outcomes related to wellbeing, entertainment, safety, or support. This level ensures that Smart Solutions can benefit a broad range of users with essential enhancements.

As we progress within the hierarchy of human capabilities enhancement, we arrive at **Context-Aware Enhancement**. At this level, the machine actor is observant of the primary context in which it operates. It adapts the delivery of its services to align with the specific circumstances, maximising usability factors. Context-aware enhancement ensures that Smart Solutions not only enhances human capabilities but do so in a contextually relevant manner making the experience more seamless and tailored to the immediate environment.

The highest level of human capabilities enhancement within this dimension is **Personalized, Context-Aware Enhancement**. Smart Solutions operating at this level extend their observations beyond the immediate context to encompass the broader context of their activities. They consider the preferences and idiosyncrasies of human recipients, ensuring that the actions and services provided are optimised to deliver the utmost value. This level recognises that individuals have unique preferences and experiences, and it tailors the enhancements accordingly to provide an optimal user experience.

ii/ Smart Digital Ecosystem

In the field of Smart Solutions, the Smart Digital Ecosystem section is of paramount importance as it delves into the collaborative dynamics of multiple machine actors. These actors operate with independent agendas but collaborate within a unified framework, often interconnected through shared APIs. This collaboration results in emergent behavior that delivers outcomes that no individual component can achieve independently. This section defines various levels of intricacy for digital ecosystem components, each contributing to these complex ecosystems' overall functionality and success.

Edge Intelligence is at the fundamental level of complexity within Smart Digital Ecosystems. In this scenario, specialised components perform well-defined activities. These activities may encompass operational, analytical, or infrastructural tasks, often as part of processes managed and executed by other ecosystem components. Edge Intelligence is crucial in ensuring that specific functions within the ecosystem are carried out efficiently and effectively. These components operate at the edge of the ecosystem, contributing to its overall functionality.

The **Orchestrator** is higher in the hierarchy. In Smart Digital Ecosystems, the Orchestrator serves as a machine actor responsible for providing inputs, managing actions, and overseeing the results of Smart Workers. Smart Workers can be either humans executing straightforward tasks involving basic cognitive or physical skills; or machine actors. The Orchestrator is the decision-making hub, providing logic and facilitating collaboration among various components within the Smart Ecosystem. This level of complexity ensures that tasks are coordinated efficiently and that the ecosystem operates cohesively.

The highest level of complexity within the Smart Digital Ecosystem is the **Enabling Platform**. This machine actor is pivotal in providing governance, integration capability, asset management, and operational intelligence for multiple collaborating processes. These processes are combined to form complex Smart Digital Ecosystems, such as Smart Buildings, Smart Factories, or Smart Cities. The Enabling Platform is the backbone of these ecosystems, ensuring seamless communication, resource allocation, and data management. It empowers the entire ecosystem by providing the essential infrastructure and intelligence required to function efficiently.

III/ Conceptualization

Based on the dimensions introduced earlier, i.e., **Modus Operandi** and **Motive**, we present a comprehensive map that provides a direct taxonomy for Smart Solutions, grounded in the fusion of two pivotal dimensions. These dimensions represent crucial and clearly defined axes along which Smart Solutions differentiate themselves, offering a holistic view of their capabilities and functionalities.

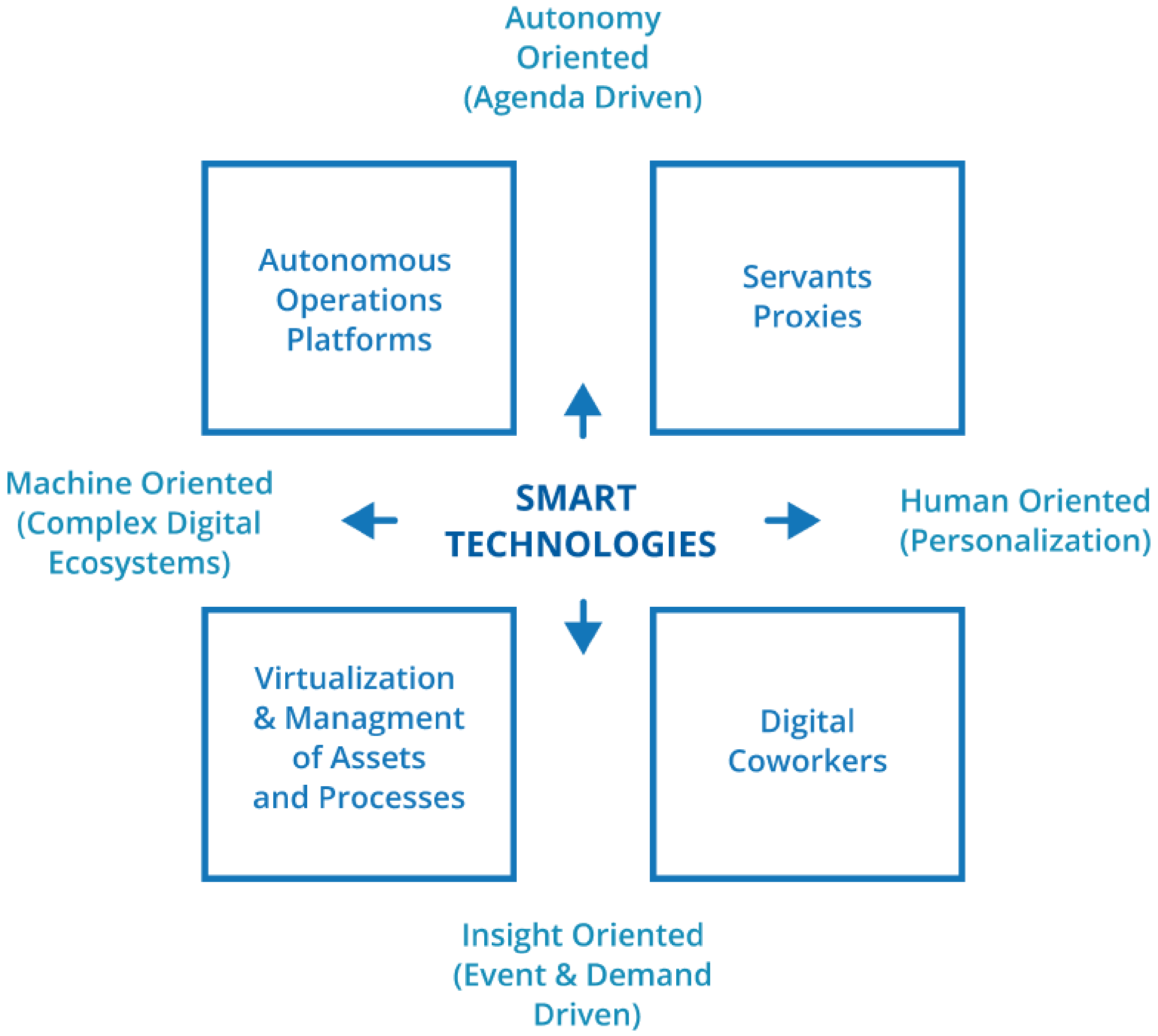


Figure 2. Map of Smart Solution Categories
Source: Own elaboration

The starting point is the combination of the dimensions into a classic "quadrant", which provides our first approximation of the "Smart Solution Patterns" taxonomy. The gradual markers (i.e., steps) can be identified between the presented dimensions' extremes. By combining these dimensions, we construct a unified framework that serves as a roadmap for understanding and classifying Smart Solutions, enabling us to navigate the diverse landscape of technology-driven solutions.

In this exploration, we propose a holistic metamodel (see **Figure 4**), which organises Smart Solutions into a structured hierarchy:

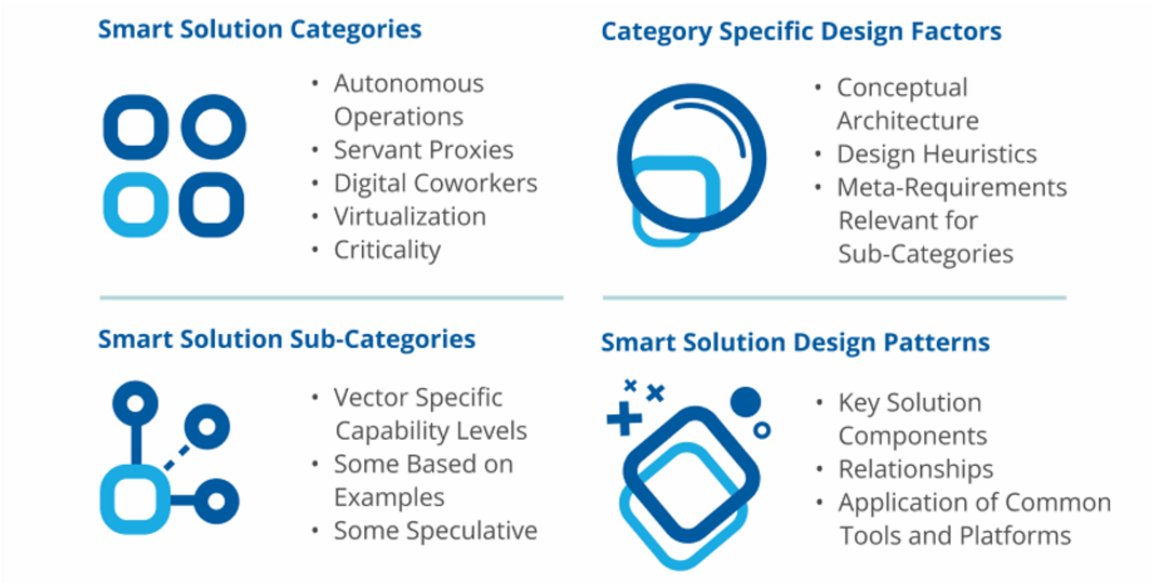


Figure 3. CAST Metamodel
Source: Own elaboration

At the top level, we define overarching **Smart Solution Categories** encompassing various domains and application areas. Beneath the primary categories, we further classify **Smart Solutions** into **Sub-Categories**, providing a more granular understanding of the diverse solutions landscape. Within each sub-category, we delve into the **Specific Design Factors** that are pivotal in shaping these solutions. These factors serve as essential guidelines for architects and developers. Finally, we identify and outline **Smart Solution Design Patterns** that encapsulate proven best practices and methodologies, facilitating the creation of intelligent and adaptable solutions.

Through the utilisation of this metamodel, the aim is to categorise Smart Solutions and empower architects and developers with valuable knowledge and tools. This empowerment extends beyond mere categorisation; it equips them to craft solutions that exhibit intelligence and possess the adaptability required to thrive in the constantly evolving technological landscape.

1/ Smart Solution Categories and Sub-Categories

In the field of software engineering, there exists a rich tapestry of well-established architectural patterns that cater to various solution categories, among them Business Intelligence, Service Oriented Architecture, and Web Portals. These patterns have stood the test of time, their design principles deeply ingrained and comprehensively documented. Crafting a successful solution within established categories often boils down to a faithful adherence to these time-honoured best practices.

Based on the dimensions introduced earlier, i.e., **Modus Operandi** and **Motive**, the following four high-level Smart Solution Categories are proposed:

- **Servant Proxies:** solutions that replace the cognitive work of people in service relationships with other people, machines, or infrastructure (e.g., Smart Home hubs, autonomous vehicles, digital assistants in the areas of sales and customer service, care robots, concierge robots).

- **Digital Coworkers:** solutions that expand/support people’s cognitive work by providing knowledge and information supporting decision-making, solving non-trivial problems and so forth.
- **Autonomous Operations Platforms:** autonomous cyber-physical platforms that offer technological and business services (automated factories and warehouses, autonomous transport systems).
- **Virtualisation and Management of Assets & Processes:** solutions that enable the creation of digital images/simulations (digital twins) of various assets (tangible - buildings, machines, cities - and intangible - processes, systems among others) to perform multiple types of operations on them (event prediction, configuration and so forth).

Smart Factory Execution Platform (real-time management of manufacturing processes & devices)	Optimizing AMR Fleet Manager (goals: AMR usage, energy consumption, cycle time, etc)	Inventory Inspection Drone	**PRO ACTIVE AUTONOMY**	Anti-Drowsiness Systems for Car Drivers	Vehicle Autopilot Function	Personalized Autonomous Transport Service
Intralogistics Execution Platform (real-time management of transport systems and devices)	Basic AMR Fleet Manager (Simple Task Allocation for AMR Fleet)	Specialized Payload Handling Tool for AMR Device	**EXECUTION AUTONOMY**	Digital Service Hub & Voice Assistant	Active NLP/ Speech Based Assistant Autonomous Material Handling Device	AI Based Gaming Platform
Open Navigational Platform for Material Handling Devices	"Mechanical Turk" type Automated Manufacturing Cell	Smart Camera with Image Recognition	**LIMITED/LOCAL AUTONOMY**	Parking Assistant Real Time Machine Translation	Media Content Co-authoring (music, copy, graphics etc)	Smart Home Comfort Manager
ENABLING PLATFORM	**ORCHESTRATOR**	**EDGE INTELLIGENCE**		**COMMODITY ENHANCEMENT**	**CONTEXT-AWARE ENHANCEMENT**	**PERSONALIZED ENHANCEMENT**
Cyber-Threat Monitoring Agent (Policy Based)	Real Time Monitoring Agent	Intelligent 3D Cameras Medical Smart Bands	**FACTUAL INSIGHT**	Credit Card Transaction Risk Monitor	Reporting Based on Complex Event Models	Product Recommend Engines
Smart Factory Configuration Manager	Real Time Energy Management for Intelligent Buildings	AI Powered Weather Station	**PREDICTIVE/ ADAPTIVE INSIGHT**	Car Navigation Weather Predictions	Smart Mobility Apps	Personal Digital Trainer
Smart Factory Designer	Real-Time Scenario Generator for Supply Chain Performance	Advanced Face Recognition Agent	**CREATIVE INSIGHTS**	Text/Data Mining	Generative Design Tool (architecture, engineering, pharma) Advanced Simulators	Artificial Researcher

Figure 4. Smart Solution examples for each subcategory
Source: Own elaboration

2/ Design Factors and Heuristics

In this chapter, we analyse key design factors and heuristics specific to the different quadrants of the **CAST framework**: the Constructive Approach to Smart Technologies. Each quadrant is characterised by its essential intrinsic characteristics, which pave the way for dedicated design patterns. By examining these factors and heuristics, we aim to gain a deeper understanding and adapt our solutions to the specific needs and challenges of each category.

i/ Servant Proxies

Servant Proxies in the CAST framework involve two key design loops:

- **The Cognitive Loop of Human Actor (HA):** This loop involves a human actor initiating collaboration with a machine actor (MA) by conveying their goals and intent, and subsequently assessing how the outcomes delivered by the MA align with their expectations. HA expectations are influenced by factors like the value proposition, conceptual models, and metaphors employed in solution design.
- **The Execution Loop (MA):** The MA interprets intents and goals, formulates activity plans, and executes them via a specific process, adhering to an "adaptive loop" pattern. It adopts the OODA adaptive loop, encompassing observation of the environment, data interpretation, decision-making, and actions. The OODA assumes the adaptive system can continually enhance the models used for orientation and decisions through learning feedback.

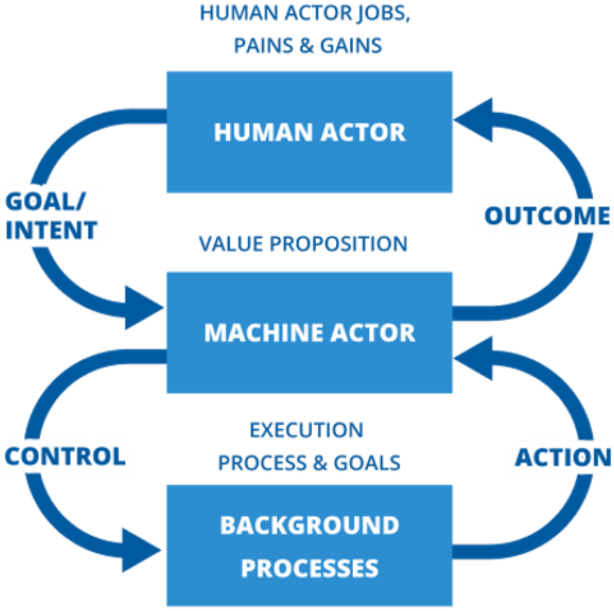


Figure 5. Servant Proxies synchronization loops
Source: Own elaboration

To design successful Servant Proxies, consider these key heuristics:

- **User-Centered Design:** Employ a systematic user-centred design methodology, like Design Thinking, to address stakeholders' needs and preferences. This helps uncover users' perception of value and provides important Human-Computer Interaction (HCI) insights.
- **Mission Objectives:** Define specific mission objectives to guide the MA's actions. Implement an Adaptive Loop model (e.g., OODA) for real-time activities involving observation, interpretation, decision-making, and action.

- **Service Patterns:** Implement autonomous Machine Actors using event-driven service patterns (observing an environment through event streams) or time-driven service patterns (continuous real-time activity). Both may use Complex Event Processing and State Machine patterns.
- **Cognitive Performance:** Smart Machine Actors excel in dynamic environments by efficiently processing available data. They adapt their actions based on cognitive performance in orientation and decision-making. Design models explicitly, separate them from applications, and ensure flexibility and performance tracking.

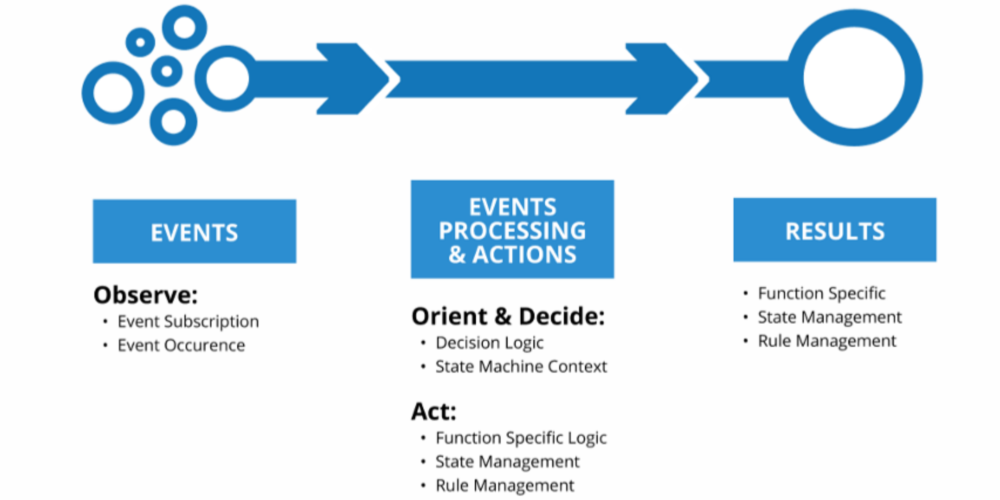


Figure 6. Event-Driven Autonomous Service
Source: Own elaboration

When implementing adaptive loops for autonomous Machine Actors, one must consider these methods:

- **Inference Engines** and **Complex Event Processing:** Build models based on managed sets of First-Order Logic rules. Analyse and improve rule sets.
- **Optimization Engine:** Use optimisation engines during design and in real-time to fine-tune model parameters and improve system performance.
- **Simulators:** Employ simulators to evaluate and enhance models. Simulate scenarios and data beyond actual operations for robustness in dynamic environments.

Figure 7. Time-Driven Autonomous Service
Source: Own elaboration

Servant Proxies rely on machine learning methods, including various neural network architectures, for tasks such as computer vision, pattern recognition, and speech recognition.

ii/ Digital Coworkers

Digital Coworkers are analogous to Servant Proxies because they involve collaboration between human and machine actors. However, their focus is on enhancing the performance of human actors in information processing tasks, improving their cognitive activities. This enhancement involves reducing inefficiencies and providing insights that are difficult or impossible for humans to generate.

Figure 8. Adaptive Loops and Cognitive Productivity Drivers for Digital Co-worker Solutions
Source: Own elaboration

Heuristics for Digital Coworkers:

- **Knowledge Work Economics:** The primary heuristic for Digital Coworkers is to optimise the cognitive loop of the Human Actor. This involves minimising overhead, data clutter, and unproductive activities often associated with a command and control approach. The goal is to enhance the human capacity to focus on goals and execute them efficiently by providing better insights and understanding of data. User interface design (HCI) should complement this by emphasising ergonomics and the quality of insight presentation, such as well-designed visualisations that avoid conveying misinformation.
- **Request-Driven or Event-Driven Machine Actors:** In this scenario, the Machine Actor operates in a request-driven manner (if insights are explicitly requested by the Human Actor) or event-driven (if insights are generated based on relevant events for the human process but not caused by the human). The value of insight-oriented Smart Solutions lies in reducing the time between a relevant fact or event and delivering actionable information to the Human Actor. This can be achieved by reducing data latency, transitioning from factual to predictive insights, optimising the level of detail and data scope, and transforming detailed data streams into higher-level events relevant to the Human Actor's role.

- **Optimizing Insight Delivery:** The OODA loop can also serve as a design heuristic for Digital Coworkers. However, it should be applied holistically to design systems that involve the activities of both Human and Machine Actors. The Machine Actor functions as an observation and orientation tool in such cases. At the same time, the Human Actor is responsible for decisions and actions, as well as for refining the model used by the Machine Actor to deliver insights through reorientation and learning.

iii/ Autonomous Operations Platforms

Autonomous Operations Platforms are essential in managing and structuring the increasing complexity driven by the Internet of Things (IoT) and Cloud Computing. These platforms play a crucial role in a digital world where large cloud platforms consist of billions of lines of code, with many services consumed by technological components rather than direct human users. They enable emergent system behaviour, such as scalability and cybersecurity, benefiting human operators indirectly.

Industries like finance, insurance, media, entertainment, and eCommerce are going fully digital, creating opportunities for autonomous business operation systems. Examples include automated hedge funds powered by AI platforms and Distributed Autonomous Organization (DAO) architectures like those implemented in Ethereum or DAO Maker projects.

Manufacturing and logistics are embracing smart devices, autonomous robots, and Industry 4.0 frameworks, leading to cyber-physical, automated systems supervised by humans. Additionally, IoT and AI are also transforming the construction and operation of buildings and infrastructures, impacting the construction industry significantly.

In this field, various technological components, often incorporating AI techniques, ensure reliable and autonomous operation:

- **Operational Components:** These machine agents perform specific, often complex, functions, such as autonomous material delivery or bird deterrence at wind turbine sites.
- **Orchestrator Components:** These agents oversee end-to-end processes, using operational components or other orchestrators to manage lower-level processes, like traffic management systems operating at different scopes.
- **Platform Components:** These machine agents provide complex behaviour by integrating and coordinating interoperable orchestrator and operational components, governed by and parameters. Examples include smart city platforms that manage various interdependent service subsystems like energy and waste management.

OODA can be the fundamental heuristic for designing the functional architecture components, implemented as services driven by event-driven or time-driven loops.

In terms of patterns and practices, modern cloud-native architecture relies on design patterns and good practices of Service Oriented/Event-Driven Architecture (SOA/EDA), with a focus on:

- **Observability Assurance:** Ensuring that components collect essential data related to their operations and share it with authorised consumers to improve insights and global optimisation of complex digital ecosystems.

- **Orchestration, Managed APIs, API Gateways:** Adhering to best practices for service discovery, governance, and designing composite applications within SOA/Microservices architectures.
- **Microservices as Building Blocks:** Embracing the microservices design and deployment style, which emphasises statelessness, cohesion, and loose coupling to enhance maintainability, testability, and independent deployment.
- **Containerization, Software-Defined Infrastructure:** Employing practices like packaging microservices in containers and leveraging software-defined infrastructure for efficient provisioning and managing large, distributed service ecosystems.

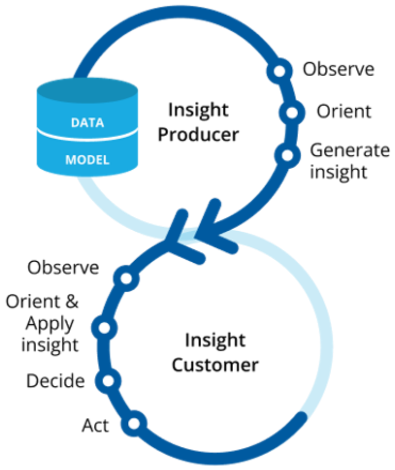
iv/ Virtualisation and Management of Assets & Processes

The concept of "insight" becomes crucial in virtualisation and management of assets and processes. Smart Solutions specialised in providing machine agents with insights used in this context. The main aim is to infuse the machine world with invaluable insights, essentially supercharging the capabilities of smart services.

This transformative concept finds its embodiment in the field of "edge intelligence", where cutting-edge devices like modern monitoring cameras go beyond the ordinary. They do not just capture video streams; they delve into data using complex image recognition algorithms.

These key elements are essential components of the paradigm shift in Virtualisation and Management of Assets & Processes:

- **Digital Twins:** At the core of this paradigm shift is the creation of digital twins. This virtualisation of digitally controlled physical assets opens up a world of possibilities. It enables analytical and predictive services that can impact entire ecosystems, ranging from factories and warehouses to sprawling transportation systems and smart cities.
- **Producer-Consumer Synergy:** A pivotal aspect of this design revolves around the dynamic between producers and consumers of insights. Smart services take on producers' role, offering these valuable insights. These insights can come in two categories: continuous or incidental. Let us imagine a 3D monitoring camera constantly recognising objects or occasionally alerting us to a potential traffic accident. Furthermore, the consumer services take these insights and accelerate their operations. For instance, autonomous vehicle navigation systems leverage these insights to navigate more safely and efficiently. If the consumer is a smart service, the "insight injection point" enriches its decision-making process. This design pattern supports independence by separating and making the orientation model explicit.



- **Diverse Insights:** Insights can originate from various sources. They might be rooted in pre-trained data classification or interpretation models, honed in standalone machine learning or simulation environments. Alternatively, dynamic models come into play when continuous improvement is on the agenda. These models often rely on consumer feedback for their training, constantly evolving and adapting.

- **Real-Time Simulation:** The field of dynamic insight production extends to real-time simulation. Think of its applications in smart manufacturing systems, where it can preemptively detect design errors and flaws, significantly reducing setup and reconfiguration time and cost. Autonomous mobile robot vendors also harness these concepts to optimise material flow within dynamic factory and warehouse environments.
- **Plugin Power:** Among the intriguing categories of insight producers are plugins. These systems sport a core platform bolstered by specialised components adhering to a standardised interface. While they may not be exclusively insight-oriented, they are instrumental in enhancing the functionality of the core platform. These components often involve sophisticated simulations, creating digital twins of real-world objects and processes, adding an extra layer of intelligence to the ecosystem.

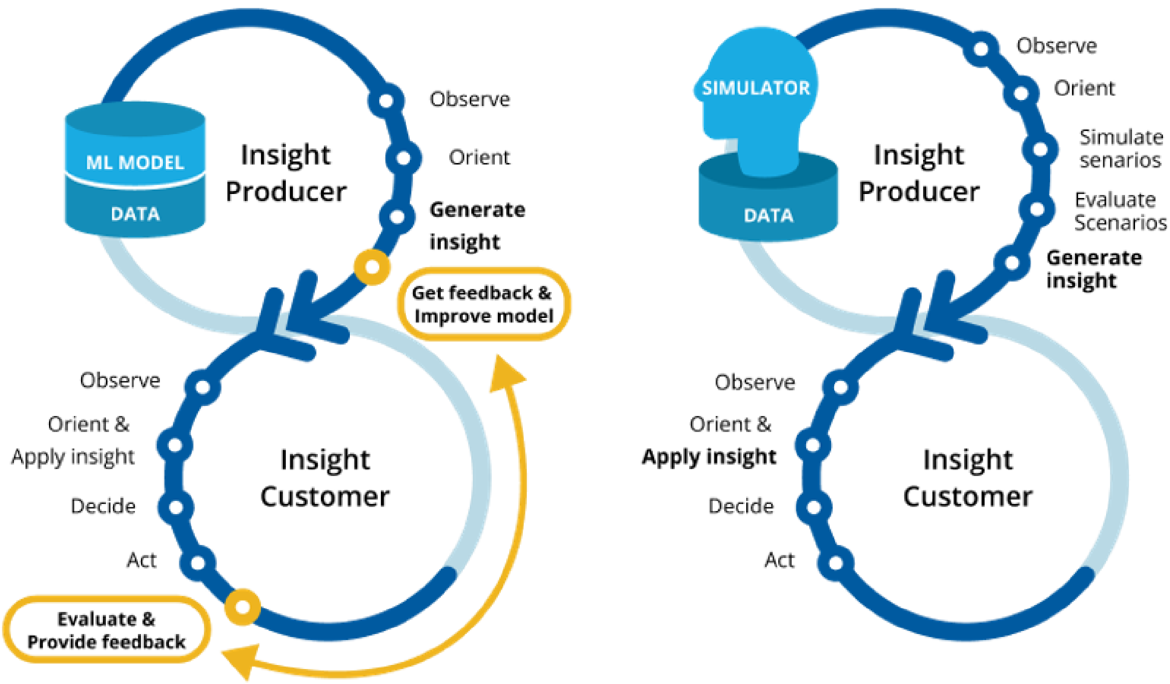


Figure 9. ML and Simulation Based Dynamic Insight Producer
Source: Own elaboration

IV/ Case studies & application

1/ Servant Proxies

Servant Proxies, as demonstrated by various real-world examples, represent a diverse spectrum of Smart Solutions, each harnessing different AI tools and techniques to meet specific human goals with minimal intervention. These digital servants take on various roles, from autonomous parking assistants to real-time content co-authors and comfort and energy managers for smart buildings.

PRO ACTIVE AUTONOMY	Anti-Drowsiness Systems for Car Drivers	Vehicle Autopilot Function	Personalized Autonomous Transport Service
EXECUTION AUTONOMY	Digital Service Hub & Voice Assistant	Active NLP/ Speech Based Assistant Autonomous Material Handling Device	AI Based Gaming Platform
LIMITED/LOCAL AUTONOMY	Parking Assistant Real Time Machine Translation	Media Content Co-authoring (music, copy, graphics etc)	Smart Home Comfort Manager
	COMMODITY ENHANCEMENT	CONTEXT-AWARE ENHANCEMENT	PERSONALIZED ENHANCEMENT

Figure 10. Servant Proxies subcategory
Source: Own elaboration

Presented below are several illustrative instances:

1. **Parking Assistant:** This Smart Solution offers a hands-off interface, requiring minimal user involvement, often initiated with a single button action. It provides a simple escape switch for aborting manoeuvres or reintroducing human control if needed. Efficient user feedback on operation progress is a priority. To achieve this, it employs multi-spectrum proximity scanning and accurate information delivery under various visibility conditions. It integrates data from vision systems and vehicle kinematics for orientation and relies on precise trajectory planning and adjustment during decision-making. The action phase involves the actuation of vehicle motion control components and user communication. Key OODA loop constraints include positioning accuracy and latency of motion control system actuation synchronised with the frequency of events affecting vehicle trajectory.

2. **Real-Time Content Co-authoring (Music Part Generation):** In this scenario, the Smart Solution operates with low latency performance tracking, monitoring tempo, melody, harmony, and providing performance cues to the human actor. It offers a broad spectrum of performance roles for machine actors, including rhythm, harmony, and lead. It listens to other actors' performances, identifies key performance parameters, and discrepancies between assumed parameters and actors' behaviour to achieve this. The decision-making phase involves the selection of phrases, patterns, and notes complementing the activities of other actors and correcting performance parameters. Actions include executing planned musical elements and providing visual and auditory cues related to current performance parameters.

3. **Comfort & Energy Management for Smart Building:** This Smart Solution incorporates a natural language interface for user communication and intuitive data visualisations for instant user feedback. It leverages various sensors, including humidity/temperature sensors, air pollution sensors, real-time energy metering devices, human tracking sensors, renewable energy source sensors, and human-computer interaction (HCI) devices. In the observation phase, it collects data from these sources. Orientation involves simulation-based prediction of comfort parameters, energy consumption, and renewable energy source output based on the Smart Home device configuration. Decision-making encompasses configuration changes for Smart Home devices or alerts to human operators for assistance if the system cannot operate within expected parameters. Actions include controlling Smart Home devices, adjusting parameters, and ensuring the desired comfort and energy management outcomes.

2/ Digital Coworkers

Digital Coworkers represents a coherent range of Smart Solutions that predominantly rely on advanced analytical techniques. These solutions are designed to enhance specific human-driven processes with AI capabilities, aiming to elevate cognitive productivity in fields like industrial design, architecture, and more. Notably, these Smart Solutions aim to introduce "Creative Insight" into their functionalities, potentially leading to unprecedented cognitive performance in human-machine systems.

	COMMODITY ENHANCEMENT	CONTEXT-AWARE ENHANCEMENT	PERSONALIZED ENHANCEMENT
FACTUAL INSIGHT	Credit Card Transaction Risk Monitor	Reporting Based on Complex Event Models	Product Recommend Engines
PREDICTIVE/ ADAPTIVE INSIGHT	Car Navigation Weather Predictions	Smart Mobility Apps	Personal Digital Trainer
CREATIVE INSIGHTS	Text/Data Mining	Generative Design Tool (architecture, engineering, pharma) Advanced Simulators	Artificial Researcher

Figure 9. Digital Coworkers subcategory
Source: Own elaboration

Presented below are several illustrative instances:

1. **Generative Design (Context-Aware Enhancement based on Creative Insights):** This Smart Solution is geared towards providing creative, evidence-based input in fields such as architecture and industrial design. It involves two key actors: the Human Actor (HA), the designer responsible for delivering actionable design artefacts, and the Machine Actor (MA), which generates candidate designs based on constraints and outcome metrics. The value proposition includes increasing human cognitive productivity by expanding the number of candidate designs considered and introducing an evidence-based approach to quality assessment. The Human-Machine Loop involves observing, orienting, deciding, and acting to optimise design processes.

2. **Automatic Diagnosis of Skin Diseases (Commodity Enhancement using Predictive Insights):** This Smart Solution reduces the error rate in diagnosing skin cancer based on radiology images. It involves human pathologists (HA) and an AI-based image analysis system (MA). The system significantly reduces error rates by enhancing human pathologists with AI-based diagnostics, ultimately improving diagnostic accuracy. The Human-Machine Loop consists of observing, orienting, deciding, and acting to enhance diagnostic procedures.

3. **Supply Chain Simulation (Personalized Predictive Insights):** This Smart Solution is centred around autonomous process design within intralogistics systems. Key actors include the Autonomous Process Designer and a Simulation engine using multi-agent simulation techniques (MA). It addresses the challenge of designing future intralogistics processes without risking factory operations.

The Human Actor defines the initial configuration of the intralogistics process, enabling the Human-Machine Loop involving observation, orientation, decision-making, and action to simulate and optimise processes.

These solutions illustrate how AI capabilities complement human expertise, leading to improved outcomes and increased productivity in various domains.

3/ Autonomous Operations Platforms

Autonomous Operations Platforms encompasses a wide range of Smart Solutions that play a crucial role in the digital world, supporting both digital ecosystems and physical machines. These platforms are the backbone of maintaining balanced delivery of services, especially in environments with dynamically changing demand and workloads. As the "internet of everything" expands with countless devices, these Smart Solutions become vital not just for humans but also for machines.

Smart Factory Execution Platform (real-time management of manufacturing processes & devices)	Optimizing AMR Fleet Manager (goals: AMR usage, energy consumption, cycle time, etc)	Inventory Inspection Drone	**PRO ACTIVE AUTONOMY**
Intralogistics Execution Platform (real-time management of transport systems and devices)	Basic AMR Fleet Manager (Simple Task Allocation for AMR Fleet)	Specialized Payload Handling Tool for AMR Device	**EXECUTION AUTONOMY**
Open Navigational Platform for Material Handling Devices	“Mechanical Turk” type Automated Manufacturing Cell	Smart Camera with Image Recognition	**LIMITED/LOCAL AUTONOMY**
ENABLING PLATFORM	**ORCHESTRATOR**	**EDGE INTELLIGENCE**	

Figure 11. Autonomous Operations Platforms subcategory
Source: Own elaboration

Presented below are several illustrative instances:

1. **Autonomous Intralogistics Platform (Enabling Platform with Execution Autonomy):** This Smart Solution is designed to enable flexible and efficient execution of material handling tasks in manufacturing and warehousing processes. It involves various components, including Autonomous Material Handling Equipment (e.g., AMR robots, Autonomous Forklifts), Autonomous Navigation systems, and Smart Material Handling Stations.

The orchestration components, such as Fleet Manager and Warehouse Management Systems, manage the flow of transport orders. Key design heuristics include implementing Navigational AI using the Time-Driven Loop Pattern and SLAM navigation concept and Fleet Management using an Event-Driven Loop.

2. **Mechanical Turk for AI-Based Manufacturing Automation (Orchestrator with Limited Autonomy):** This Smart Solution focuses on creating a smart workplace for manufacturing automation, with a Human Agent serving as the coordinator/integrator of the manufacturing process. Operational components include smart manufacturing stations, while the orchestration components feature an AI-based Manufacturing Process Manager. The system's core is the AI-based process management engine, which issues recommendations to streamline the process. The design heuristics involve the Observe-Orient-Decide-Act loop, where data from the manufacturing process is collected and interpreted in real-time by AI algorithms, decisions are made based on process anomalies, and instructions are provided to human operators for exception handling.

These solutions exemplify the critical role of AI-driven systems in managing complex processes and ensuring efficient operations in digital and physical domains.

4/ Virtualisation and Management of Assets & Processes

In the field of Virtualisation and Management of Assets & Processes, Smart Solutions are essential for making sense of complex digital ecosystems and extracting business value from them. This category serves as a bridge between the operations capabilities and the knowledge monetisation capabilities of these ecosystems.

ENABLING PLATFORM	ORCHESTRATOR	EDGE INTELLIGENCE	
Cyber-Threat Monitoring Agent (Policy Based)	Real Time Monitoring Agent	Intelligent 3D Cameras Medical Smart Bands	FACTUAL INSIGHT
Smart Factory Configuration Manager	Real Time Energy Management for Intelligent Buildings	AI Powered Weather Station	PREDICTIVE/ ADAPTIVE INSIGHT
Smart Factory Designer	Real-Time Scenario Generator for Supply Chain Performance	Advanced Face Recognition Agent	CREATIVE INSIGHTS

Figure 9. Virtualisation and Management of Assets & Processes subcategory
Source: Own elaboration

Presented below are several illustrative instances:

Simulation-Based Intralogistic Process Optimisation Engine (Predictive Insights supporting the operations of Enabling Platform): This Smart Solution is designed to optimise decision-making in intralogistics processes, including task allocations, routing priorities, and power management activities. It leverages a simulation-based engine to achieve these optimisations.

The Insight Producer collects data on events and performance related to intralogistics, identifies risks of critical events, simulates alternative process scenarios, evaluates their impact, and generates insights to raise alerts and recommend alternative scenarios. The Insight Consumer listens to these alerts, assesses their criticality, and applies recommended actions by changing process configurations. This Smart Solution enhances the efficiency of intralogistic operations.

Advanced Face Recognition Agent (Creative Insights delivered by Edge Intelligence): In this Smart Solution, a machine agent provides person recognition services by extrapolating a person's possible current appearance from existing visual assets. The Insight Producer observes "IDRequest" queue data, uses machine learning models to analyse image data, rates the results, and publishes them. The Insight Consumer records visitor streams, generates "IDRequest" events for visitors attempting to access secure areas, listens to "POI Alert" queue data, and decides on actions based on the analysis of this data. It can allow access, prohibit access, or escalate further. This Smart Solution enhances security and access control systems.

These solutions demonstrate how data analysis, simulations, and insights can drive efficiency and effectiveness in various domains, from intralogistics optimisation to advanced face recognition for security applications.

V/ Complex Smart Solutions

1/ Inevitable complexity

Smart Solutions can often start small – as a specific functionality, such as parking assistant, smart 3D camera reading plate numbers or chat based on the Generative Pre-training Transformer model. The thing that usually follows if they successfully achieve their goals, is the growth of complexity. This growth can happen while the solution remains in a given Smart Solution category.

For example – an image recognition system marking EMR scans with risk of malevolent disease, can be extended with a conversational feature that can be used to analyse cases and medical records further to suggest possible diagnoses, explore symptoms or find relevant examples for comparison. While the complexity of such solution will surely grow, the solution will most likely still be assessed as a Digital Coworker. The changes in these capabilities will mark the evolution from Commodity Enhancement based on Predictive Insights into Context Aware (or perhaps even Personalized) Enhancement based on a mix of Creative Insights.

However, let us consider a situation when another functionality is added – one when the digital assistant can be asked to conduct an online interview with a patient to check some symptoms which might increase or decrease the risk, and based on the result, suggest arranging an appointment with the physician with appropriate priority.

We need to consider what the autonomous patient priority manager based on medical records is oriented at. It may be insight or autonomy-oriented solution. The answer proposed by CAST is the following: we have just created a complex solution that integrates insight-oriented and autonomy-oriented components. CAST framework helps us to differentiate components based on their motivation and modus operandi, which supports designing a better high-level solution architecture, and enables a better-detailed design by focusing them on design factors and heuristics important for different components.

2/ The problem of purpose

The constructive nature of the CAST framework starts with the taxonomy. The 36 Smart Solution Subcategories provide a rich grid on which complex solutions can be mapped. However, the granularity of taxonomy urges solution designers to focus their high-level design activities on the purpose of the product or service being designed rather than on the technology that can be used.

So the questions that taxonomy imposes – what is the modus operandi, and what is the motivation for a solution – lead to questions about purpose, personas, value proposition and sometimes even business model.

Using the previous example:

PURPOSE ("KNOW WHY")			SMART SOLUTION SUBCATEGORY ("KNOW WHAT")
Value Proposition	**Persona**	**Business Model**	
AI Based Tumor Alert Application	Physician (high domain expertise, moderate digital skills)	More cases served More focus on non-standard cases	Commodity Enhancement based on Predictive Insights
Conversational Digital Assistant used to analyze cases and medical records and suggest possible diagnoses, explore symptoms or find relevant examples for comparison	Physician (domain expertise enhanced by the system, high digital skills) Management	Better patient care More efficient therapies Moderate level domain experts are made more productive	Context Aware Enhancement based on Predictive & Creative Insights
Conversational Digital Assistant conducting an online interview with patients to check some symptoms which might increase or decrease the risk, and based on the result introduce an appointment with the physician with appropriate priority	Physician (domain expertise enhanced by the system, high digital skills) Patient (accidental user, low digital skills) Management	Better patient care, especially for sensitive cases More efficient therapies Moderate level domain experts are made more productive Domain expertise allocation can be optimized and better managed	Autonomous patient priority manager based on medical records

"know why" – various aspects of the *raison d'être* of the planned solution, with "know what" – understanding the nature of the solution and its design consequences. Such an analytical process lets one choose the starting point, which will often represent some kind of "Minimum Viable Product" and gradually increase the complexity of the solution.

3/ CAST-Based Roadmapping

Complex solutions can rarely be defined as single projects. Most often, such solutions evolve on several levels (capability, functionality, usability, technology), and this evolution is usually planned using some form of roadmap.

A product roadmap usually outlines the direction and plans for a product's development, providing a high-level overview of the product's future trajectory, including key features, enhancements, and goals.

A roadmap consists of milestones, which represent time-related conglomerates of business goals (e.g. KPI levels), feature sets, technology components, and so forth, that represent completion of some critical step in product evolution, often becoming product releases (internal or external).

The CAST framework may serve as a supporting tool for roadmapping for complex Smart Solutions. Consider the following example, based on our initial case of an autonomous intralogistic platform vendor. An autonomous intralogistics platform is a complex system consisting of autonomous material handling robots (AMR) orchestrated by a digital fleet manager, to optimise the fleet performance in real-time, supported by simulation-based process design tools and optimisations engine.

The architecture of such a complex solution can be mapped on CAST taxonomy, along with ideas about (1) what are the intrinsic relationships between the components and (2) what constitutes a meaningful release for customers. This can help us define the essential milestones for the roadmap – cornerstone product releases.

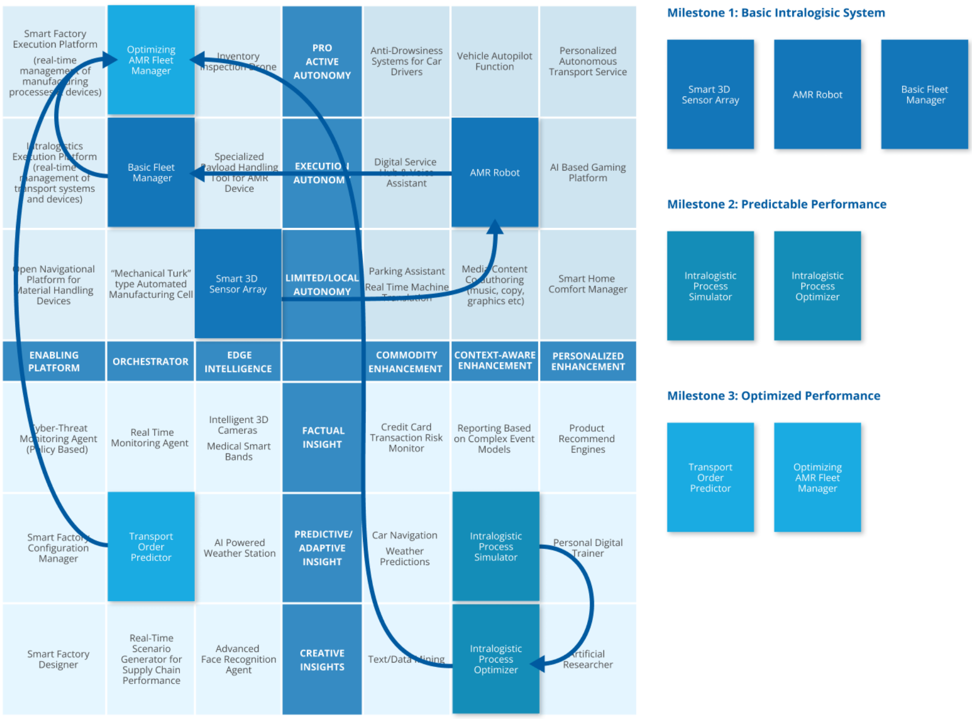


Figure 12. Mapping a complex Smart Solution for product development roadmap
Source: Own elaboration

VI/ CAST Portal Demonstrator

The CAST team has completed the development of the CAST Portal demonstrator, which serves as the MVP version scheduled for the first quarter of 2024. This demonstrator includes interactive content corresponding to the latest framework version and crucial technical components.

These components encompass an interactive taxonomy-based search feature, enabling effective resource exploration, a UI style guide with ready-made templates for a consistent and visually appealing website design, a content management system (CMS) facilitating easy content creation, editing, and management, and backend components for metamodel administration.

The framework version published on the CAST Portal also integrates RAI (Regulations on Artificial Intelligence) guidelines based on the principles of AI for Fair Work, promoting ethical AI use. Additionally, the portal incorporates selected use cases from the AI Observatory, allowing users to explore practical applications of artificial intelligence.

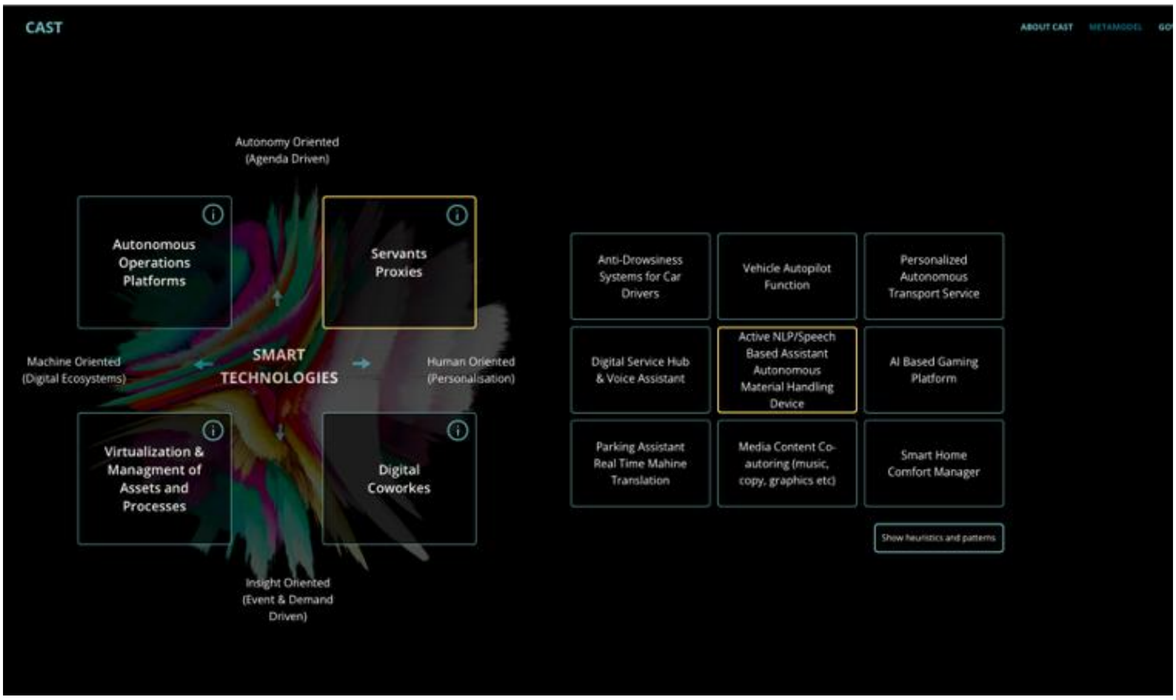


Figure 13. Taxonomy-based search facility of CAST Portal
Source: CAST Portal demonstrator screen capture

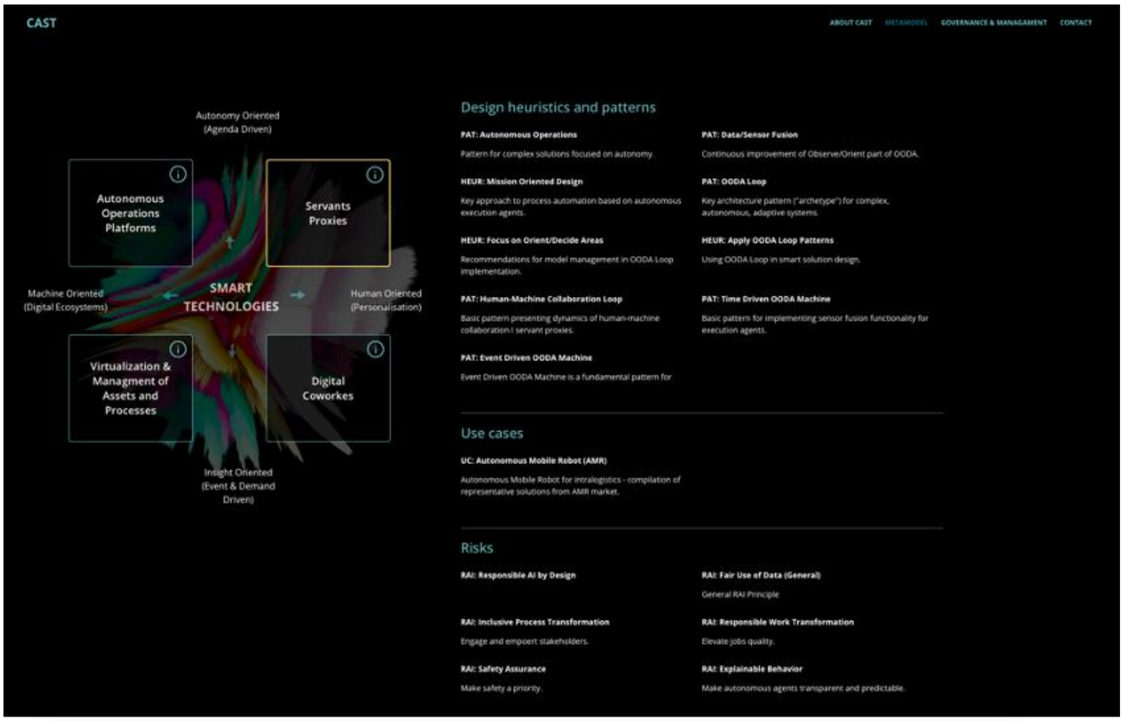


Figure 14. Taxonomy-based search results for context-aware, execution autonomy-oriented solutions
Source: CAST Portal demonstrator screen capture

The demonstrator will play a dual role in our project. Firstly, it will serve as a valuable feedback tool, allowing us to gather insights on the user interface's usability and the practicality of the CAST framework. This input is essential for refining the user experience and improving the framework.

Secondly, the demonstrator will act as the primary platform for the development and dissemination of the CAST framework. We will work closely with experts from the Global Partnership on Artificial Intelligence (GPAI) and various working group projects to ensure that the framework reaches a broader audience and benefits from expert input, thereby allowing it to evolve and grow effectively.

VII/ Conclusion

In conclusion, this report shows that research and experimentation are pivotal in harnessing the potential of AI techniques and tools to deliver innovative solutions. The evolution of AI from its early foundations to its recent real-world applications has generated high expectations and concerns, particularly regarding the responsible use of AI. Currently, AI reached the peak of its popularity. Therefore, managing the risks associated with it, such as investment bubbles and ethical considerations, is essential.

To navigate these challenges, a systematic study of AI use cases supported by a well-defined, open AI design framework like CAST needs to be conducted. This would, in turn, transform the current state of inflated expectations into systematic productivity. The work conducted by the GPAI working groups has initiated this process, providing valuable insights and impetus for further development. The goal is to integrate the CAST framework with ethical guidelines, expand the database of examples, and enhance the depth of design factors and patterns. Ultimately, the aim is to transfer ownership and evolution of the CAST framework to a community of AI practitioners, fostering responsible and productive AI innovation.

In addition, we would like to emphasize the importance of CAST's continued relevance and practical utility in future activities within the Future of Work (FoW) Working Group. The framework has the potential to shape the narrative of AI regulation, paving the way for responsible and ethical AI practices that prioritize the empowerment of workers. Moreover, CAST can contribute to the identification and endorsement of AI tools that empower individuals, thereby improving job quality and enhancing the overall work environment.

The potential cooperation with other projects includes:

- AI for Fair Work - verification and improvement of CAST RAI guidelines for implementation of AI for Fair work principles (Future of Work Working Group's),
- Empower AI Workers - CAST Team can offer the students access to CAST portal and mentoring support in their development projects in use case development, and solution design, combining CAST and design thinking techniques (Future of Work Working Group's),
- AI for SME - collecting use cases and examples of RAI implementations in real-world projects, verification, and improvement of existing CAST framework (Innovation and Commercialization Working Group's),
- Scaling RAI - collecting use cases and examples of RAI implementations in real-world projects, verification, and improvement of existing CAST RAI guidelines (Working Group on Responsible AI),
- Generative AI and the Future of Work - verification and improvement of CAST design heuristics related to cognitive productivity enhancement, and predictive/creative digital coworker solutions based on project results (Future of Work Working Group's).

This means that CAST should not be seen as a standalone effort but rather as a dynamic framework that can adapt to the evolving needs of AI practitioners and the broader community. This adaptability ensures its continued relevance and practical utility in an ever-changing AI landscape.

The CAST framework is undergoing systematic refinement in an evolving "work-in-progress" phase. We cordially invite researchers and practitioners to offer their academic insights and reflections to foster the further enhancement of the CAST framework.

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