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Reality-infused simulations for dashboarding potential realities

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Abstract

In production environments, it is essential to anticipate the opportunities and challenges of new technology implementation trajectories. Often, companies face an inability to oversee the consequences on different aggregation levels, fields of expertise, perspectives and time-frames. This research presents an architecture to support simulation-based prevision of potential realities that comprehend results in a meaningful and perspective-dependent manner. The architecture specifically aims to ensure that the simulation benefits surpass the efforts and cost involved. The instant-controlled flexibility of reality-infused simulations leads to more insight in the effects of changes, while structuring the development trajectory and making it more predictable and deterministic.

Keywords: Simulation; Decision making; Synthetic environments

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1. Introduction

Industry is inundated with new technologies like cobots, Lidar, and real time location systems, each potentially improving the efficiency and effectiveness of processes in or aspects of production environments or development cycles [1]. The impact of such technologies depends on the specific use-case, while heavily affecting decision making. Therefore, there is a clear need to anticipate the consequences of new technology implementation trajectories - in terms of opportunities and challenges [2]. Current 'Industry 4.0' production environments usually allow for abundant data capturing. However, converting such data affluence into purposeful bases for decision making is not trivial. Many types of simulations, what-if analyses, and scenarios at different levels of aggregation need to interact to conjointly project potential realities infused by the presently available data [3, 4]. Outcomes of simulations and the like depend on myriad of factors, while requiring significant efforts to be efficacious. The added value (e.g., usefulness, accuracy, and reliability) should outweigh the efforts (e.g., time, money, data accessibility, and connectivity) [5]. Gaining insight in this is an extensive endeavor, heavily influenced by constantly changing parameters, requirements and expectations.

Production environments offer well-nigh endless possibilities for simulations [3]. The added value of simulations lies in interrelating them in structured and instrumental ways, while exploiting shared starting points, models, and delineated information sets. Moreover, the various stakeholders must be able to comprehend results in a meaningful and perspective-dependent manner [6]. With that, an overarching approach is required to govern the design, configuration and execution of simulations, what-if analyses, and scenarios.

This publication presents an architecture that supports such an approach by governing the simulation-based prevision of potential realities. The architecture specifically aims to ensure that the simulation benefits surpass the efforts and cost involved.

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1.1. Context and perspective

For any company, it is essential to anticipate the impact of changes to any product (development) life-cycle phase when implementing new technologies, as uncertainties and limited understanding of risks are involved. Therefore, a company should be able to assess causes and effects that impact its production environments and its processes, while also weighing the relations and interdependencies between the various components. Yet, production environments are far too complex to model in a deterministic manner [7]. Moreover, information flows are too dynamic and external stressors are too unpredictable to allow for unequivocal and reliable prospects. With that, scenario-based use of simulations is a proficient means of supporting decision making.

The research described here originates from the explicit demand for support in depicting potential realities as encountered in multiple projects in production environments. The related case studies (see section 5) stem from companies that are preparing for e.g., more personalised production, more flexibility, changing product portfolios, decreasing lead times, and green-fields increase in production capacity. The main issue is generically formulated as "… inability to oversee consequences of decisions with different aggregation levels, fields of expertise, perspectives and time-frames (e.g., strategic, operational, tactical)".

2. Simulating reality

In a manufacturing context, scenario-based use of simulations starts from a data-oriented, or a process-oriented perspective. Either mapped or collected data (e.g., by measuring or sensoring) is the basis for uncovering relations, correlations, and dependencies. Alternatively, an a-priori structure of activities drives the pursual of meaningful data. Both approaches can and will co-exist in development cycles. Developers, therefore, need to be able to simultaneously reason from both perspectives. In this realm, again, simulations are powerful means to amalgamate the projected processes and data availability into depictions of potential realities [8, 9]. Developers aim to maximise the usability of simulations. Concurrently they must select appropriate and suitable sets of simulation tools & techniques in the quest to construe expectations, constraints, and goals.

Whereas industry may aim for pragmatic application of simulations and scenarios, any approach for establishing potential realities should exceed sheer trial-and-error. In experiencing and interacting with a production environment that does not yet exist, it is essential that the benefits of simulations outweigh the efforts involved, and that the lead time of simulation trajectories match the project horizon. As changes in production environments range from incremental or continuous improvements to big overhauls or paradigm shifts, the value and usability of simulations is often uncertain during the development cycle [10]. Where this may give rise to an all too experiential attitude, a deliberate approach for establishing, structuring, and using coherent simulation sets and simulation tools is required. In such an approach, a clear focus on dealing with variable expectations of simulations is required. This combines e.g. gliding scales from real to virtual elements, gliding scales of accuracy and gliding scales of perspectives involved.

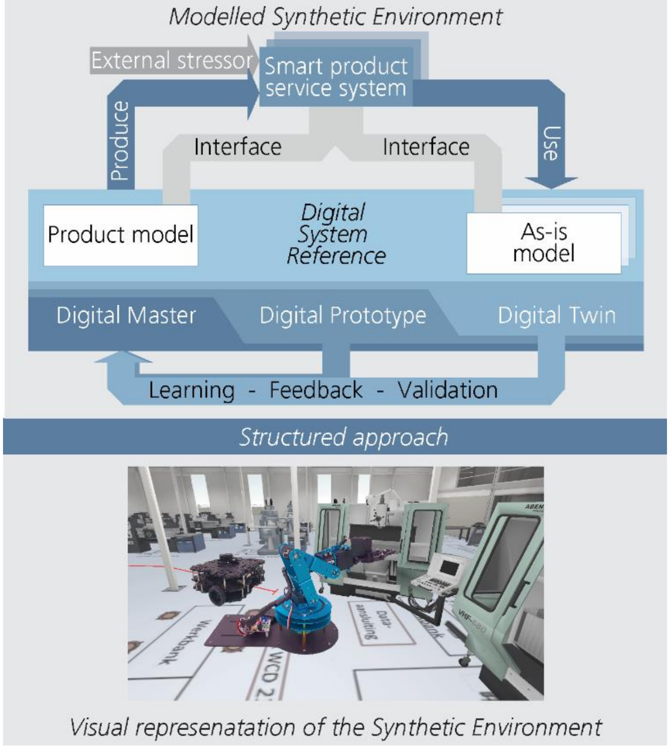

Figure 1. A structured approach is required to connect the Digital System Reference and use-case dependent Synthetic Environments.

In the anticipated future scenarios, simulations should be more reality infused in order to gain more insight in the consequences of changes, without relying on assumptions, or on (bounded or incomplete) models. Companies should be guided and supported in the use hereof. The process of developing, designing and using these simulations should be performed structured, so that it becomes a bi-directional learning environment that will improve over time, and which stimulates making changes to both the simulations as well as the real world. Hence, an architecture is needed to support this.

2.1. Digital System Reference and Synthetic Environments

Simulations always depend on the availability of data, often rendering that data useful by making it immersive, contextualising it and tailoring it to the present decisions [11, 12]. As simulations habitually relate to historical data, include scenarios and sensitivity analyses, and involve what-if analyses, there can be a plethora of (varying and interrelated) data involved. Hence, maintaining a supporting structure for managing the data that underlies and results from the simulations is a prerequisite. Understanding the dependencies between simulation inputs and experienced output is essential to establish a valuable, workable, and purposeful environment. The starting point is to understand and contextualise what part of reality should be simulated, for who and based on what. To deliberately compare current conditions to potential realities three perspectives on the data are discerned in a so-called Digital System Reference [13] (Figure 1):

- digital master (‘to-be’): the definition of the envisaged entity,
- digital twin (‘as-is’): the current/previous condition of an entity,
- digital prototype (‘could-be’): simulations between the design intent and the actual conditions.

To interact with the data in the DSR, e.g., to experience the outcomes of simulations, a functional set of tool and techniques must be selected and configured. As the data ranges from detailed information about an asset itself (e.g., CAD models) to context information (e.g., location or status information), the required set of functionalities can be very large.

So-called Synthetic Environments (SE) [14] combine tools that realise such functionality (e.g., VR, AR, dashboards, haptic devices etc.) in such a way that stakeholders can experience and interact with current and envisaged environments that fuse real and virtual elements and behaviour. In an SE, the balance between real and virtual assets can vary, and also the form in which the virtual elements are represented is not fixed. An SE is considered to encompass more than just the tangible or digital tools, since it also takes into account elements such as working methods, workflow, knowledge and environment. The approach to compose an SE as described in [14] allows to make decisions on what to experience, guided by strategical, tactical as well as operational considerations. An SE is most useful if tailored to the current needs of the stakeholders, rendering every SE use case specific.

In formulating and experiencing potential realities, both the DSR and the SE are required. The SE allows for a tailored experience as the basis for decision making; the DSR makes an SE relevant (Figure 1). However, bringing together the SE and DSR requires significant harmonisation. This, for example, entails structuring the simulations with their inputs and outputs, while executing different scenarios and aligning the required tools and data. Moreover, this harmonisation focuses on aligning the simulations to the decisions making processes that establish the potential realities for production environments.

3. Approach

The harmonisation of the DSR and an SE foremost focuses on the functional coupling of data and its usage. Therefore, an architecture approach is chosen here, as an architecture focuses on the interrelations of the elements in the system rather than on the manifestation of those elements. Hence, an architecture aims to rationalise the construction process of a model, not of the model itself.

However, devising an architecture from sheer theoretical insights may yield a valid, but less of an applicable solution. So, rather than postulating a conjectural architecture, here, actual case studies and industrial practice are used to work out the architecture in an evolving, design-by-research based, approach. In this manner, the architecture advances, while the industrial case studies already and immediately take advantage of both the advancing architecture, but also from sharing expertise and experience.

The case studies also provide information on the relations and dependencies between requirements from the stakeholders and the output of simulations. Likewise, experience in industrial practice aids in understanding how such dependencies would develop over time. The case studies all use the same DSR structure as an information backbone, from which each case intends to find the most appropriate instantiation of the SE. Every case study uses a different approach to link the architecture and the SE, mainly determined by the company characteristics, strategy, challenges involved and stakeholder expectations.

3.1. Elements and common denominators in SE configuration

In composing an SE, recurring functional elements can be used. Such elements aim at integrating the perspective of each stakeholder, e.g. by documenting relevant information [14]. These elements are mapped on a landscape with three layers: the scouting space, the discussion space, and the solution space. Based on case-specific requirements for each element, it needs to be defined what shall be considered, how this should be actually done, and which level of detail and certainty is required. For the scouting space this involves the definition of the objects under investigation and related parameters/variables as well as the means and accuracy for data gathering. This space sets the maximum boundaries for the development of the SE. For the discussion space, possible aggregation/simplification strategies need to be considered, which is strongly connected to the selected model approach. This space is modelled according to strategic considerations, requirements, and decisions made by the stakeholders involved. In the solution space, feasible configurations of methods and tools for a decision supportive SE are defined. Compared to the scouting space and discussion space, multiple solution spaces can exist within a discussion space. This space is tailored to the expectations and needs of a specific SE, which could be aimed on e.g. a specific stakeholder, context, time or expectation. Based on the current context, expectations, and requirements the most appropriate solution will be constructed.

Ultimately, the objective is to find a good balance between the anticipated expectations of an SE within the conditions and boundaries of use. With any change of the requirements, such an SE will become sub-optimal, may no longer meet the expectations and therefore may not be applicable anymore. Therefore, any change of the context and requirements can, and has to, be monitored to ensure the pertinence of the SE.

Obviously in the industrial case studies examples of such changing context or requirements submerged rather quickly. The main examples of these can be summarised in the identification of the following common denominators:

- Different perspectives on the DSR. The output of the simulations can explicate the effect of changes with respect to the digital master, digital twin, or digital prototype. Such perspective dependencies allow for discerning interests of different stakeholders as well as different time horizons, for example to distinguish between rough (but fast) estimates for quick wins or for initiatives having bigger impact yet require more extensive simulations. A seamless transition between

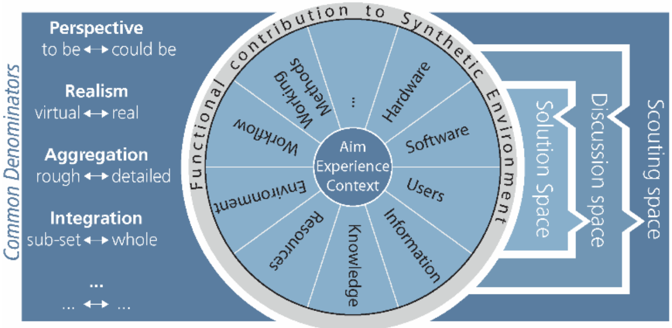

Figure 2. Functional representation of a building block with the common denominators as the interface of the SE to the DSR and simulation realm.

these different perspectives results in a faster iteration cycle, and more insights in the consequences of changes.

- Balancing reality and virtuality. Whereas simulations do need data as their input, the source of that data can vary between real-life/real-time sensor values and values that stem from models, assumptions, estimates or other constructed sources. Occasionally, real data can be used, or simulations can instantly drive experiences in the SE With that, simulations can range from near-factual to completely artificial (e.g. animation), oftentimes combining the two extremes in demarcated (scaled) environments [15].
- Multiple levels of aggregation. An SE might concurrently expose e.g., scheduling and capacity planning consequences of decisions. Different stakeholders take interest in different levels of detail and/or aggregation, yet decisions at one level may very well impact all of them. Hence, different expectations based on expertise, role and needs of the simulations must impact how an SE is instantiated and tailored.
- Level of integration. A simulation can involve any sub-set of elements and/or aspects in a production environment, while this demarcation can change over time. Often, changes to a production environment cannot be validated directly as an integrated whole, since the uncertainty of the result (and therefore the risk of failure) is too big [13]. With a changing level of integration, a simulation allows for impartially testing, examining, and validating new tools while negotiating the impacts and risks involved.

During the use of a specific SE, emphasis amongst the common denominators may shift with changing real-life circumstances and objectives [16]. With such shifts, also the relation between added value and required efforts is impacted. This implies that the structured approach mentioned in Figure 1 must be able to assimilate dependencies and sensitivities encountered in the application of an SE. This again stresses that the envisaged structured approach relies on the two-sided dependencies between the DRS and its representation in the SE. Figure 2 depicts the functional representation of a building block that integrates the elements and common denominators that allow for a deliberate embedding of the SE in the simulation environment. This building block becomes an essential part of the architecture that supports the structured two-way translation between DSR and SE.

4. Architecture

To systematise the two-way translation between DSR and SE while purposefully exploiting an appropriate set of reality-infused simulations, the architecture as shown in Figure 3 is proposed. The aim of the architecture is to support the development of a conglomerate consisting of a DSR, an SE and the set of simulations, scenarios and what-if analyses that connect them. With the architecture providing that support, the resulting environments will allow stakeholders to make informed and underpinned decisions for potential realities that originate from real-life (historical and real-time) data and advanced prognoses [17]. Intentionally, the architecture is regarded as always being under development, as its inherent functionality evolves with the case studies encountered. This design-by-research attitude (see also section 3.1) ensures immediate applicability of the architecture, but also allows for new elements (e.g., simulations and tools, but also contexts and functional modules etc.) to be integrated. The focus in this architecture is on supporting a technology-pull approach, by first determining the desired output of a simulation in an SE and subsequently obtaining the relevant input data and methods to achieve such output. However, once an SE exists, that same SE can also enact a sandbox for technology-push ventures. New technologies and tools can be integrated in the SE without disturbing the ongoing process.

In the architecture, the orchestrator is responsible for effectively and efficiently accommodating the different dimensions, while using the appropriate data from the DSR. The simulation manager governs the simulation workflow, given the goals, requirements, constraints, and scenarios available. The SE configurator instantiates the SE, based on e.g., the different perspectives involved, the required output as well as levels of detail and aggregation, and the many other aspects and elements that contribute to a stalwart SE [14]. As instantiated SEs operate in the dynamic field between reality and virtuality, measurements from the (virtual enriched) reality are captured in the DSR. Various observations are monitored by the moderator to check that expectations are met and to instruct the simulations manager to adopt changes accordingly. The definition of the expectations of the simulations results are provided by the requirement manager and the criteria & evaluation manager captures the different perspectives of multiple SEs and their position on the gliding scales.

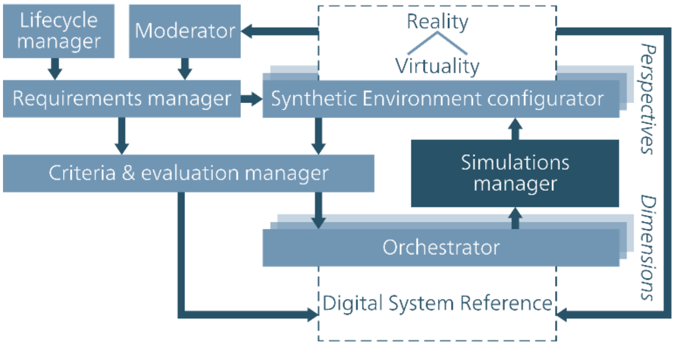

Figure 3. The architecture that leads to support in the development of instant-controlled flexibility in reality-infused simulations.

5. Case studies

The architecture is generic in its purpose and outline, but inherently affiliates with the use cases and contexts. The design-by-research approach facilities, and requires, multiple case studies to both develop and improve the architecture. The industrial environments on the other hand directly benefit from the results of the case studies. The following case studies exemplify how the generic architecture connects to specific industrial projects.

5.1. Re-planning of production facility

Several case studies share the aspect of facility re-planning. The first case study is based on a project in which a production company aims to realise a significant extension of their production capacity. Given the investments and risks involved, the company needs to know how the whole ecosystem will respond to the changes proposed . The focus is on the changes effecting the order output and flow, rendering the logistic perspective the catalyst. Projected impacts on the ecosystem should allow for assessing the strategy for the extension of the production (e.g., in terms of factory layout and logistics, but also in the selection of new assets to acquire). A significant challenge in this case study relates to determining the required level of detail and aggregation. Hence, initial simulations addressed a high reality factor based on the historic data to validate the simulation processes involved. The simulations were used to validate the predictability and sensitivity of the envisaged environment, both to establish the appropriate level of aggregation and to engage the stakeholders with sufficient confidence. Subsequently, the simulation tools (ranging from plant simulation software, via emulated ERP projections to maintenance assessment) were brought together to enable the different stakeholders to conjointly experience the different perspectives involved to allow for underpinned decision making. Moreover, the integrated simulations did allow for purposeful sensitivity analyses based on the formulated scenarios as well as on conceived changing circumstances.

The second case study deals with the implementation of a DSR that supports what-if analyses and allows for comparison of scenarios in a large industrial maintenance and overhaul facility. In the aerospace context of the case, the workflows are rather fixed, yet the data, planning and information flows are dynamic and allow for improvements. Consequently, here, the SE behaviour could be established rather straightforwardly, from which the content of the DSR could be conceptualised. For the company, this leads to improvement trajectories related to e.g., planning and quality control, based on explicit delineation of targeted additions and adoptions of data acquisition and management techniques.

The third case study addresses a bike manufacturer for speciality bikes. The company aims to exploit the usage of real and artificial data to assess different tools (both software and hardware/assets) in several future scenarios driven by an evolving company strategy. Here, the scope of the simulations is adjusted by including additional production machines, capacities, or even additional manufacturing locations. The resulting SE, for example, allows for placing additional ‘fictional’ machines that are not available in reality (yet). The simulations allow for testing the useability and efficiency of solutions for now and for later scalability. The simulation path is based on logistics, although the real validation addresses the future scenarios and the company strategy.

All three case studies straightforwardly benefit from the usage of the architecture to support the decision-making process of selecting the right scales and structuring the approach towards the simulation of the replanning scenarios of the production environment.

5.2. Scheduling and routing of order based on RTLS

This case study deals with the manufacturing and final assembly of customer-specific, complex technical products. Processing of customer orders is currently done manually in the multi-step job shop environment (processing times typically several minutes). This leads to inefficient sequences as well as increasing throughput times and high stocks. Here, the solution approach is an SE that fuses a real time locating system (RTLS) and ERP data as the basis for discrete event simulation. Thus, this SE supports the operational phase of the system based on a real-time and real-life data. The RTLS allows for spatial (coordinates) and time related (timestamp) tracking of orders and assets in the production environment. Order information (e.g., status, customer delivery time) as well as pending work tasks and nominal process times are provided through the ERP. Both RTLS and ERP data are infused with context specific data, which leads to an updated as-is model of the manufacturing system. This SE becomes the basis (e.g., for the shop floor production manager) for decision making based on the predicted performance in relation to different scheduling scenarios. Different types of data visualization and virtual enhanced realities can be used simultaneously. An operator on the shop floor can visualise

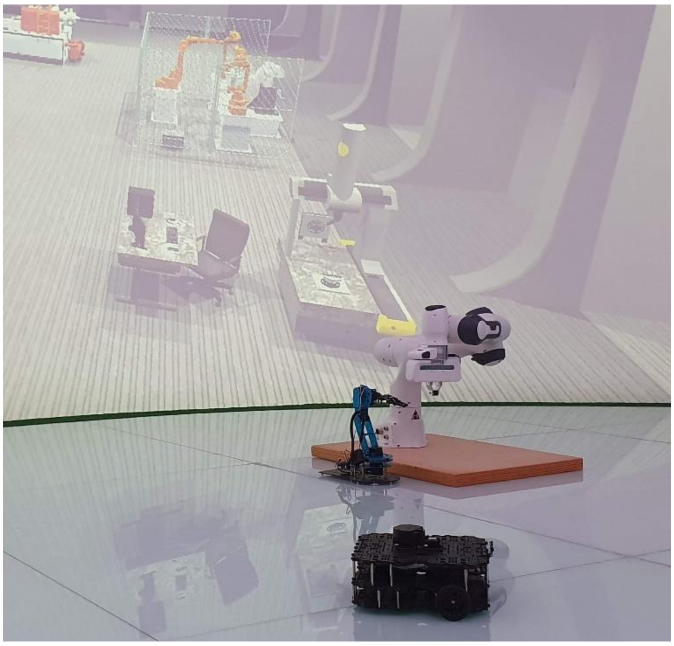

Figure 4. Instantiated SE used in a case study with both real and virtual elements. The physical robots in the front are seamlessly integrated with the virtual model on the screen.

historical and predicted information on machines and processes, while the same information is used by robots and automatic guided vehicles (AGV) to navigate to the correct position. In this specific case the AGV uses an RTLS system to know where the target is in the environment, during movement the AGV navigates itself using lidar, while a vision tracking system is used whenever the AGV has to interact with a different machine (Figure 4).

The shop floor performance increases accordingly, although, for now, some uncertainties are still influential due to the limited predictability of manual tasks and transportation processes. Based on the architecture, however, subsequent implementation steps are foreseen to increase the accuracy where possible and profitable.

Conclusion

A Synthetic Environment provides insight in the effects of potential changes in production environments, while anticipating opportunities and challenges of new technology implementation trajectories. However, the development process of an SE that is comprehensive and tailored to the environment and all its stakeholders is far from trivial. The reason for this is that the SE is pivotal in linking the expectations of different stakeholders, at different levels of aggregation with the available and obtainable data, the tools and techniques, as well as the many simulations, what-if analyses and scenarios involved. Hence, it is important to integrate only relevant data and possibilities, to conjointly project potential realities infused by the presently available data.

The proposed architecture establishes the structured connection between the DSR and an SE in such a way that the benefits of the resulting SE will exceed the efforts and cost involved. This is achieved by providing a structured, predictable, and deterministic approach to exploit the common denominators involved. With that, from the start, estimates on e.g., the projected value, the required (types of) data or the required time allow for easier and more predictable development cycles, while providing insight in the completeness and conclusiveness of all the simulations involved. Whereas the architecture provides means to establish SEs to represent potential realities, the SE itself will not be generic, as it is essentially tailored to the intended use case and stakeholders involved. Because an SE will, because of its relation to the DSR, be able to embed simulations in real-life and real-time data, vastly improved means of decision making can become available. Also, the insight in the effect and sensitivities of changes increases, while simultaneously addressing or encapsulating uncertainties. Different levels of reality are combined with different timescales and tailored to different aggregation levels and perspectives of involved stakeholders. This is orchestrated based on the common denominators that may gradually change and allow for the optimisation of the SE over time and with increasing use.

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