An Intelligent Digital Twin Concept for Metallurgy

Robert Pierer and Sebastian Michelic

qoncept dx GmbH, Peter Tunner Str. 19, 8700 Leoben, Austria

We extended the term digital twin by the additional adjective "intelligent", as the approach described in this article combines fundamental-based (first principle) models with data driven approaches: Instead of choosing between the two, the strengths of the two approaches are combined to create models with significantly better properties, in comparison to the models currently in use.

1 INTRODUCTION

The steel-producing industry is characterized by many process steps, starting with melting of the raw materials, through many individual treatment steps in the secondary metallurgy to the casting of the semi-finished product. Figure 1 schematically illustrated the different steelmaking routes (converter, electric and stainless steelmaking) as well es the various possible secondary metallurgical processes.

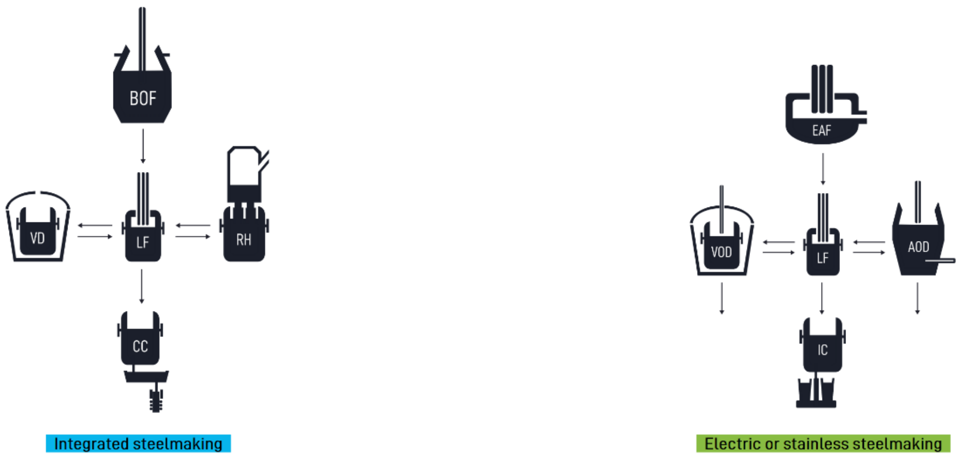

Figure 1: Schematic illustration of the different routes and processes for steelmaking

This diversity in process options and combinations coupled with large differences in the degree of automation and digitization often hinders the smooth integration and commissioning of modern technologies and concepts such as Industry 4.0. The technologies associated with Industry 4.0, especially the Smart Factory, which should improve the efficiency of production, require new approaches to process optimization. In this context, the recognition of inefficiencies is often cited as the key to minimizing production costs. Accordingly, process simulations and the adaptation of process parameters play an essential role.

So far, however, such process models have only been developed specifically for the respective process (the respective plant unit). Additionally, not all metallurgical phenomena running in parallel are considered. Thus, it may be that there are non-coupled separately developed models for phenomena, which occur within a specific metallurgical process. Many of these different metallurgical processes influence each other and must therefore be coupled. It is therefore not enough to just assemble these specific models individually in an overall system of process simulation, but interactions must become an integral part of the solution.

In an earlier article (A literature review on digital twins based on freely accessible scientific papers), we showed that, in addition to the term digital twin, a distinction must be made with regard to digital model and digital shadow. In context of the level of integration, the digital model, shadow and twin are described as follows [1]:

+ **Digital Model:** A change of state of the physical object has no direct effect on the digital object, and vice versa.
+ **Digital Shadow:** A change of state of the physical object leads to a state change in the digital object, but not vice versa.
+ **Digital Twin:** A state change of the digital object also leads to a state change in the physical object, and vice versa.

Additionally, it can be concluded that although it is a highly relevant concept for industrial and research initiatives, the scientific literature is still at an early stage. The present article describes in detail how we set up an intelligent digital twin for the processes of melting and refining of the steel industry. The approach includes all three levels of integration, i.e., the digital model, the digital shadow and the digital twin. The digital model as the core of the solution follows a fundamental, holistic approach in combination with data-driven approaches in the context of the rapidly evolving Artificial Intelligence (AI) technology.

2 FROM THE DIGITAL MODEL TO THE INTELLIGENT DIGITAL TWIN

2.1. The Digital Model Suite

Figure 2 schematically shows the concept of the Digital Model Suite . The digital model suite consists of the digital model and the "build your virtual steel shop" application. The latter can be seen as the Human Computer Interface (HCI) or Graphical User Interface (GUI), respectively. In a more software-specific language one could also speak of frontend (build your own steel plant) and backend (digital model). Whatever it is called, the digital model represents the heart of the entire solution. It is based on a fundamental and holistic approach, in which the fundamentals of thermophysics, thermodynamics, reaction kinetics and all energy and mass balances are developed in a general approach for melting and refining.

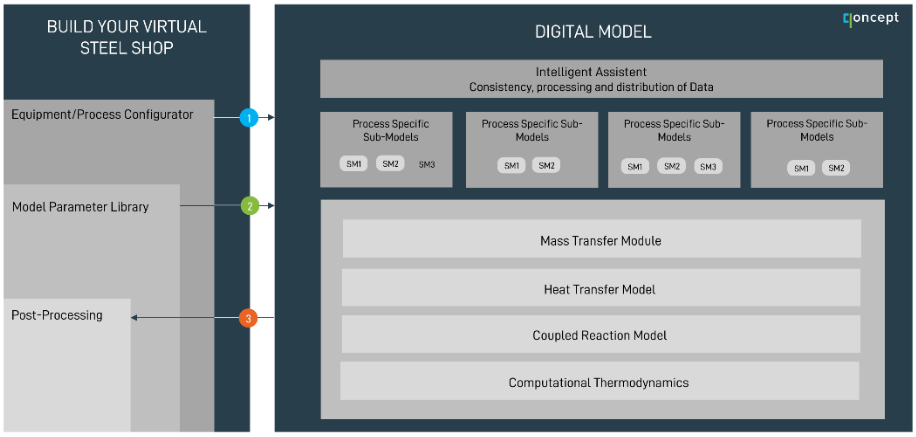

Figure 2: Schematic illustration of the conceptional design of the Digital Model Suite

Process-specific phenomena, if not otherwise possible, are integrated as sub-models. Interactions of different phenomena within the sub-models and interactions with the holistic and cross-process approach are considered. The use of an intelligent assistant as part of the digital model ensures the verification of data (data consistency), data preparation and distribution.

The equipment and process configurator enables the simple creation of specific process routes (motto: “build your virtual steel shop”) as well as entering or uploading cyclical and event-based process data (blue circle). As a result, the large number of process routes in steel production can be taken into account in a simple manner. In the model parameter library, all model parameters are summarized which have to be adapted or optimized for the specific processes and customers (green circle). The visualization of the calculation results will be done via the post-processing application (orange circle).

2.2. The Digital Shadow

In order to realize the digital shadow, the real metallurgical must be considered as shown in **Figure 3**. This requires the establishment of an interface to collect process data in real time. In our approach, this is realized with the Data Process Suite. However, since the degree of automation in the steel production industry often differs greatly from application to application, this variability must be taken into account in a highly modular and generic architecture.

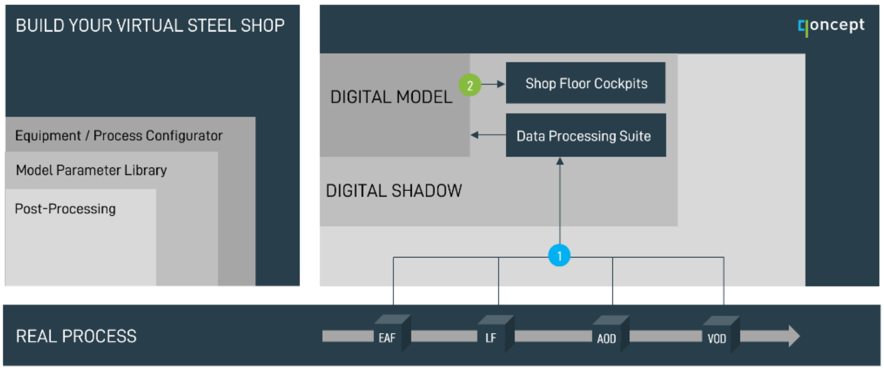

Figure 3: Schematic representation of the extension from the digital model to the digital shadow

All process and model-relevant data are fed into the digital model and calculations are carried out in real time (blue circle in the Figure). The results of the simulation are displayed to the operator of the process. All process and model-relevant data are fed into the digital model and calculations are carried out in real time. The results of the simulation are displayed to the operator with the help of specific cockpits (shop floor GUIs and indicated by the green circle). Assuming a validated model, the current status of the process (mainly temperature and chemical composition of steel and slag) can be visualized at any time. In connection with process goals and defined control values, process monitoring is ensured.

2.3. The Intelligent Digital Twin

As mentioned above, the implementation of a digital twin is characterized by the fact that the data flows are fully integrated in both directions. The digital twin can thus act as a control and optimization instance (in combination with optimization models) of the physical process. The evaluation from the digital twin to an intelligent digital twin is carried out by combining the above described first principle model with data-driven approaches (AI). **Figure 4** shows finally the holistic picture of our concept.

The following three additional models are part of the intelligent digital twin for controlling and optimizing metallurgical processes:

+ **Correction Model:** This module ensures that the accuracy and usefulness of the model is improved by a self-learning approximated correction model (blue circle). As an example, incorrectly or inadequately specified parameters can be mentioned here (either due to lack of knowledge, lack of understanding or due to calculation restrictions).
+ **Virtual Sensors:** Many process variables cannot be measured with high accuracy due to extreme operating conditions (e.g. temperatures> 1600 ° C) or are only known with a delay after extensive laboratory analysis has been carried out. Virtual sensors with AI functionality enable the required process parameters to be measured in real time and future changes to be predicted based on the available process data (green circle).

+ **Optimization Models:** These models enable a dynamic set-point control by accessing the results of the digital model (orange circle). In doing so, this application account for economic advantages and process related requirements based on different optimization criteria (e.g. reduction of material input, energy, treatment time).

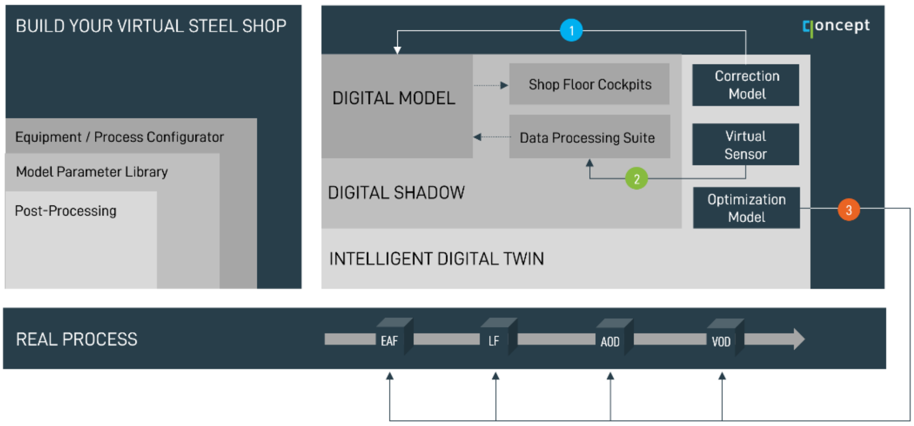

Figure 4: The integration of additional models in combination with artificial intelligence to archive an intelligent digital twin

3 NOVELTY AND BENEFITS

In a previous article we showed that the concept of the digital twin is extensively treated and described in the relevant literature. The following bullet points summarize the differentiation and novelty of the above described approach:

+ It is not the systems and machines that are necessary for production that are in the foreground, but the different metallurgical processes. The systems only provide the framework conditions necessary for the digital models. This does not consider the reflection and the prediction of the state or performance of the plant, but the different and constantly changing states of the melt and slag.
+ The approach specifically follows the three-stage integration (digital model -> digital shadow -> digital twin) and creates a usable product with added value for potential customers through each individual integration stage.
+ The fundamental, holistic modeling approach, although much more complex and difficult to develop, takes into account the different, mutually influencing metallurgical processes. The previously process-specifically formulated disciplines of thermophysics, thermodynamics, reaction kinetics and all energy and mass balances are developed in a general approach for melting and refining.
+ The fundamental digital model can be used for a large number of different geometries (i.e. a wide variety of potential use cases). The pre- and post-processing module (building your virtual steel shop) leads to a significant improvement in scalability.
+ The digital model suite acts as a tool for process variable design. As a result, synergies can be generated for the creation and continuous improvement process of treatment instructions and recipes.
+ With the help of the real-time calculation and the state of the process determined by it, deviations can be recognized quickly and decisions can be supported.
+ The combination of first-principle models with data-driven approaches (AI) is another noteworthy novelty with great potential for use. Since these two methods are very

similar at some level (only one other function model is used for modeling), many synergies arise from the combination of strengths from both approaches.

4 SUMMARY

Steel makers are constantly faced with the need to improve their processes in order to ensure the company's success. In this context, digital transformation, the smart factory and Industry 4.0 are key. Particularly, the various key technologies (enabler) of Industry 4.0 are becoming increasingly important in the steel-producing industry. Two of these key technologies are computing and simulation as well as artificial intelligence.

We extended the term digital twin by the additional adjective "intelligent", as the approach described here combines fundamental-based (first principle) models with data driven approaches: Instead of choosing between the two, the strengths of the two approaches are combined to create models with significantly better properties, in comparison to the models currently in use.

The greatest advantage lies in the significant improvement of the metallurgical modeling in order to precisely determine the actual situation (temperature, chemical composition of the melt and slag) and thus enable fully automatic real-time control and optimization of the metallurgical processes.