

# **Automatic Generation and Validation of Simulation Based Digital Twins**

## **A Data-driven Framework and Case Study Application**

---

**Author:** Daniel Fischer

**Supervisor:** Prof. Christian Schwede

**Program:** Research Master Data Science

**Institution:** Hochschule Bielefeld (HSBI)

**Submission Date:** February 18, 2025

# Contents

<b>Glossary</b>	—	<b>5</b>
<b>1 Introduction</b>	—	<b>6</b>
1.1 Problem Statement . . . . .		6
1.2 Objectives of the Thesis . . . . .		6
1.3 Motivation and Relevance . . . . .		6
1.4 Research Questions and Hypotheses . . . . .		6
1.5 Thesis Structure / Methodology . . . . .		6
<b>2 Theoretical Foundations and State of the Art</b>	—	<b>7</b>
2.1 Digital Twin: Definition and Concepts . . . . .		7
2.1.1 Types of Digital Twins		7
2.2 Data-Driven Modeling: Principles and Methods . . . . .		7
2.3 Material Flow Planning and Simulation . . . . .		7
2.4 Validation and Verification in Simulation . . . . .		7
<b>3 State of Research</b>	—	<b>8</b>
3.1 Existing Approaches for Validation and Verification of Digital Twins . . . . .		8
3.2 Automatic Model Generation and Its Reasons/Chal- lenges . . . . .		8
3.3 Limitations of Current Standard Formats and Data Structures . . . . .		8
3.4 Gaps and Open Questions in the Research . . . . .		8

<b>4</b>	<b>Methodology and Framework Development</b>	<b>9</b>
4.1	Requirements Analysis (Functional, Technical Data Format) . . . . .	9
4.2	Conceptualization . . . . .	9
<b>5</b>	<b>Implementation of the Framework</b>	<b>10</b>
5.1	Technical Implementation of Model Generation . . .	10
5.2	Automatic Validation of the Generated Model . . . .	10
5.3	Use of External Information Sources for Model Verification . . . . .	10
5.4	Interfaces to Material Flow Systems and Data Collection . . . . .	10
<b>6</b>	<b>Case Study: Validation of a Digital Twin in the Production System</b>	<b>11</b>
6.1	Description of the Production System and Available Data . . . . .	11
6.2	Construction of the Digital Twin for the Scenario . .	11
6.3	Conducting the Validation Experiments . . . . .	11
6.4	Results and Interpretation: Limitations and Errors of the Model . . . . .	11
6.5	Limitations and Falsifiability of the Model Based on Real Data . . . . .	11
<b>7</b>	<b>Discussion of the Results</b>	<b>12</b>
7.1	Critical Reflection on the Framework Development .	12
7.2	Limitations of Automatic Validation . . . . .	12
7.3	Significance and Robustness of the Developed Methods . . . . .	12
7.4	Implications for Research and Practice . . . . .	12
<b>8</b>	<b>Conclusion and Outlook</b>	<b>13</b>

Contents	4
8.1 Summary of the Key Results . . . . .	13
8.2 Answering the Research Questions . . . . .	13
8.3 Outlook: Possible Further Development of the Frame- work . . . . .	13
8.4 Recommendations for Practical Application . . . . .	13

# Glossary

**computer** is a programmable machine that receives input, stores and manipulates data, and provides output in a useful format 1

**FPS** Frame per Second. 1

**Linux** is a generic term referring to the family of Unix-like computer operating systems that use the Linux kernel. 1

**real number** include both rational numbers, such as 42 and  $\frac{-23}{129}$ , and irrational numbers, such as  $\pi$  and the square root of two; or, a real number can be given by an infinite decimal representation, such as 2.4871773339... where the digits continue in some way; or, the real numbers may be thought of as points on an infinitely long number line. 1

# **Chapter 1**

## **Introduction**

### **1.1 Problem Statement**

### **1.2 Objectives of the Thesis**

### **1.3 Motivation and Relevance**

### **1.4 Research Questions and Hypotheses**

### **1.5 Thesis Structure / Methodology**

# **Chapter 2**

## **Theoretical Foundations and State of the Art**

### **2.1 Digital Twin: Definition and Concepts**

#### **2.1.1 Types of Digital Twins**

### **2.2 Data-Driven Modeling: Principles and Methods**

### **2.3 Material Flow Planning and Simulation**

### **2.4 Validation and Verification in Simulation**

# **Chapter 3**

## **State of Research**

- 3.1 Existing Approaches for Validation and Verification of Digital Twins**
- 3.2 Automatic Model Generation and Its Reasons/Challenges**
- 3.3 Limitations of Current Standard Formats and Data Structures**
- 3.4 Gaps and Open Questions in the Research**



## **Chapter 4**

# **Methodology and Framework Development**

### **4.1 Requirements Analysis (Functional, Technical Data Format)**

### **4.2 Conceptualization**

Waswani et al., 2017

# **Chapter 5**

## **Implementation of the Framework**

### **5.1 Technical Implementation of Model Generation**

### **5.2 Automatic Validation of the Generated Model**

### **5.3 Use of External Information Sources for Model Verification**

### **5.4 Interfaces to Material Flow Systems and Data Collection**

## **Chapter 6**

### **Case Study: Validation of a Digital Twin in the Production System**

**6.1 Description of the Production System and Available Data**

**6.2 Construction of the Digital Twin for the Scenario**

**6.3 Conducting the Validation Experiments**

**6.4 Results and Interpretation: Limitations and Errors of the Model**

**6.5 Limitations and Falsifiability of the Model Based on Real Data**

# **Chapter 7**

## **Discussion of the Results**

### **7.1 Critical Reflection on the Framework Development**

### **7.2 Limitations of Automatic Validation**

### **7.3 Significance and Robustness of the Developed Methods**

### **7.4 Implications for Research and Practice**

# **Chapter 8**

## **Conclusion and Outlook**

### **8.1 Summary of the Key Results**

### **8.2 Answering the Research Questions**

### **8.3 Outlook: Possible Further Development of the Framework**

### **8.4 Recommendations for Practical Application**

# Bibliography

Waswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A., Kaiser, L., & Polosukhin, I. (2017). Attention is all you need. *NIPS*.