FAKULTA ELEKTROTECHNICKÁ ČVUT V PRAZE

MASTER THESIS

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Energy transparent manufacturing

Department of measurement

Supervisor of the master thesis:	Ing. Pavel Burget PhD.
Study programme:	Intelligent Buildings

Prague 2018

I declare that I wrote the presented thesis on my own and that I cited all the used information sources in compliance with the Methodical instructions about the ethical principles for writing an academic thesis.

In Prague, 24.5.2018 ....

Title: Energy transparent manufacturing

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Abstract:

This thesis is covering topic of holistic approach for energy efficient production, with utilisation of building connection to production line, PROFIenegry protocol and energy transparency principles. All processes are mapped on RAMI 4.0 information model.

Práce se zabývá holistickým přístupem k energeticky efentivní výrobě s využitím spojení výrobní linky a budovy, protokolu PROFIenergy a zásad energetické transparence. Všechny procesy v práci jsou namapované na infromační model RAMI 4.0.

Keywords: industry4.0 testbed energy efficiency

To my fiancée Pavla, for all the support, comfort and guidance she's giving me.

I'd love to thank my supervisor Mr. Burget for guidance and ideas given during writing this thesis. Without his help and support, this thesis could not be possible.

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My sincere thanks also goes to Leos Dvorak who helped me drive my focus on topic of this thesis.

Last, but no least, my greatest gratitude goes to my parents who supported me during my whole studies.

ZADÁNÍ DIPLOMOVÉ PRÁCE

ČVUT
ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Froněk** Jméno: **Tomáš** Osobní číslo: **383379**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra měření**

Studijní program: **Inteligentní budovy**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Energeticky transparentní výroba

Název diplomové práce anglicky:

Energy-transparent production

Pokyny pro vypracování:

Vytvořte model BIM pro laboratoř Testbed a okolní místnosti s ohledem na energetické veličiny, které je možné vztáhnout k výrobní lince jako například energie pro osvětlení, vytápění atd. Vytvořte model výrobní linky a model toku výroby tak, aby z něj bylo možné odvodit elektronickou průvodku výrobku. Navrhněte propojení modelů výroby a budovy a vytvořte kombinovaný informační model. Implementujte propojení řídicího systému budovy a řídicího systému výrobní linky a implementujte navržený informační model tak, aby bylo možné ovládat alespoň osvětlení laboratoře Testbed v závislosti na stavu výroby a přítomnosti lidí v laboratoři. Do řízení výroby implementujte možnosti ovládání spotřeby energie přepínáním provozních stavů dle aplikačního profilu PROFIenergy.

Seznam doporučené literatury:

[1] Posselt, G. (2016). Towards Energy Transparent Factories (Sustainable Production, Life Cycle Engineering and Management). First Edition. Springer. ISBN 978-3319208688.
[2] Michael Schenk, Egon Müller, S. W. (2009). Factory Planning Manual: Situation-Driven Production Facility Planning. First Edition. Springer. ISBN 978-3-642-03635-4.
[3] PROFIenergy. Common Application Profile, version 1.2. Profibus & Profinet International.

Jméno a pracoviště vedoucí(ho) diplomové práce:

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Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **15.02.2018** Termín odevzdání diplomové práce: ______________

Platnost zadání diplomové práce:
do konce letního semestru 2018/2019

Ing. Pavel Burget, Ph.D. podpis vedoucí(ho) práce	podpis vedoucí(ho) ústavu/katedry	prof. Ing. Pavel Ripka, CSc. podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

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Datum převzetí zadání	Podpis studenta

Contents

Introduction

> We cannot wait until there are massive dislocations in our society to prepare for the Fourth Industrial Revolution.
>
> *Robert J. Shiller, Yale University*

Czech Republic's GDP is 32,3% [1] industrial production. This historical heritage from times of Habsburg monarchy is driving Czech economy with year-to-year growth of 4,5% (1Q.2018) [2]. Our wellbeing is based on manufacturing production, but year-to-year growth is slowing down. Since the end of II. world war, there is decline of productivity growth [3] as well. There are numerous macroeconomics factors explaining this trend. However, for us, most important is how to keep our industry healthy, competitive and running.

German government understood this problem back in 2011 and introduced Industrie 4.0 as a roadmap for German industry to digitalise manufacturing. Thanks to our interconnectivity with german economy, czech Ministry of Industry and Trade has adopted this methodology and published Initiative for industry 4.0 [4]. Based on this initiative, several Testbeds for Industry 4.0 around Czech republic started growing. This thesis is based on Testbed for Industry 4.0 based in Prague CIIRC.

In this thesis, I am covering the topic of energy efficient production and ideas of standardisation based on [5] and [6] as two corner stones of Industry 4.0. In the first 3 chapters, I am covering theoretical topics regarding possible changes in society and industry with implementation of Industry 4.0. In following chapters, I have prepared several examples of implementation Industry 4.0. All examples are created with respect to current norms, however some white papers regarding implementation have not yet been published by the publication time of this thesis. Because of that, some examples may vary from standardised solutions.

1. Society 4.0 - digitalisation in all fields

Modern concept of economy has been presented by Adam Smith in his book The Wealth of Nations [7] in 1776. Until then, people believed, that to get rich, someone has to get poor. It was believed that the pool of resources is fixed and cannot be enlarged. Thanks to discovery of the New World and extraction of resources from Americas, European aristocracy has started reinvesting profits into their enterprises and started economic growth that kept up today.

We have already experienced three industrial revolutions. First, when James Watt invented steam engine in 1765 and allowed British mining industry to get more coal and distribute it all around the United Kingdom. Together with rise of steam powered workshops from fibre to heavy machinery, we called it first industrial revolution. Acceptance of this new technology took about 100 years.

Than, in 1866 Werner von Siemens invented first electrical motor. It again increased the pace of GDP growth. Acceptance of electrification in industry took more than 60 years - faster than steam. This has changed manufacturing from ground.

In 1947, transistor has been invented and changed everything. Third industrial revolution is dated into 60s and 70s of 20th century. Acceptance of new computing technology into manufacturing dropped merely to 15 to 20 years.

But since the end of II. world war, the world is experiencing decline of year-on-year productivity grow. It almost seems, that we filled all potential in manufacturing and our production is on the peak. However, this does not apply for digital companies. When we look at fortune 500, since beginning of 21st century first 5 to 10 places have changed. From traditional companies like General Electrics or Ford to all digital like Facebook or Alphabet (formerly Google). German government understood, that german economy based on manufacturing is in danger. That is one of the key reasons why 5 years ago, on Hanover Messe (biggest fair for industrial manufacturing in Europe) the idea and concept of Industry 4.0 has been presented. This idea is developed by german biggest three organisations in industry - ZVEI, Bitkom, and VDMA. It brings together the world of manufacturing and the world digitalisation, up to now separate.

Our government understands this challenge, thanks to our economy interconnection with Germany and started initiative for Industry 4.0 in Czech Republic. This effort resulted in founding National Centre for Industry 4.0 and first Czech Testbed for Industry 4.0 in Prague.

1.1 New challenges in manufacturing

In [8] and [9] I have describe challenges that manufacturing industry has to keep up today. It is the rise of productivity, flexibility, quality and efficiency. In this thesis, my main topic is efficiency. How to manufacture with less resources, more sustainable and for lower prices. This is one of the key factors of Industry 4.0. If we can produce with higher effectivity, it is possible to move production back from Asia and less developed countries back to Europe. This can preserve workplaces as well as environment. To produce efficiently, we need to have detailed insight into our manufacturing and be able to measure our consumption of resources with regards to production.

1.2 Energy transparency as new approach for sustainability

In last 15 years we have understood that climate change is happening all around the world and it is caused by mankind. This lead to the increased protection of nature and environmental regulation mainly in western societies. There are new norms for energy efficiency like ISO 50001 [10] or 50006 [11] that are supposed to help enterprises to reduce inefficient processes and increase overall energy efficiency. In testbed we have decided to take it one step further. By monitoring usage of energy in every step of production, we are able to optimise processes and to create electronic dispatch note that keeps all the information regarding manufacturing process of specific product in digital world. It is also a reliable indicator for customer if he wants to buy sustainably manufactured products.

1.3 System integration as way toward energy efficiency

With increased acceptance of norms like ISO 50001 and ISO 50006, energy efficiency of manufacturing industry has grown rapidly. Currently, there is just a little space for improvement. One possible way to improve usage of resources could be, integration of building and manufacturing technologies. In [12] is described an approach, how to make machining shop floor without human workers and save resources - mainly on workforce. Moreover, if we make slightly more effort we can save resources on lighting, heating, and cooling. If we make our machines able to talk to BMS (building management system), they could be able to request light, human presence or heat/cold. All of this without human interaction. In this thesis I am developing this topic of system integration.

With new digitalisation trend taking all field of industry, there is important part of standardisation. In industrial field, this is covered by RAMI 4.0 model [6]. In construction industry, currently there is no standard of managing data/information model or processes, but we can help with BIM (building information model) methodology [13]. In following chapters, I approach building as part of information model RAMI and building is considered as standard object in digital enterprise. I have reduced my building model only to testbed premises. On green field project there has to be integral approach. In [14] is well described integration of digital twins and models for better behaviour of system.

There are several reasons for connecting building and manufacturing lines together. In [8] I have describe some advantages of having one information model of overall digital enterprise. Just briefly:

- Unified insight to energy/resources utilisation - It is difficult to make improvements in energy consumption if we don't know how is energy distributed through the system.

- Security and safety - With connection of personal database, attendance, indoor positioning, and employee location we can manage machine safety and manufacturing premises admission effectively.

- Construction and mechanical performance - Putting into perspective data from machines and building. Vibrations, robots movement, production from machines and load, vibrations, temperature and humidity from buildings, we will be able to design subtile constructions and we will be able to avoid problems with installation of heavy machinery onto shop floor.

- Single digital twin - We are able to simulate overall performance of whole digital enterprise in first stage of concept design and optimise its behaviour. Design building around production line and build production line in localities historically unusable - like city centres or brownfields, not to build new, box like buildings behind the city.

This holistic approach to manufacturing and construction industry could help us keep industry sustainable and environmentally friendly with high efficiency and flexibility of production.

2. Building information modelling

Construction work industry is currently going thru revolution. Standard paper based architecture, design, and construction documents are getting into digital age. For last 20 years CAD and CAM systems are helping engineers and architects to design buildings with ease and with help of modern computer algorithms. BIM (Building information model or Building information management) is often mistaken for standard 3D model of construction. BIM is combination of 3D model and holistic list of informations, that we know about construction - so called information layer of components. The BIM revolution in construction engineering is often compared with industry 4.0 revolution in manufacturing industry.

The greatest advantage of using BIM in building construction is transparency of data used and single point of access to information. It is solving problems with lack of information during construction phase and missing real state data several years after finishing construction.

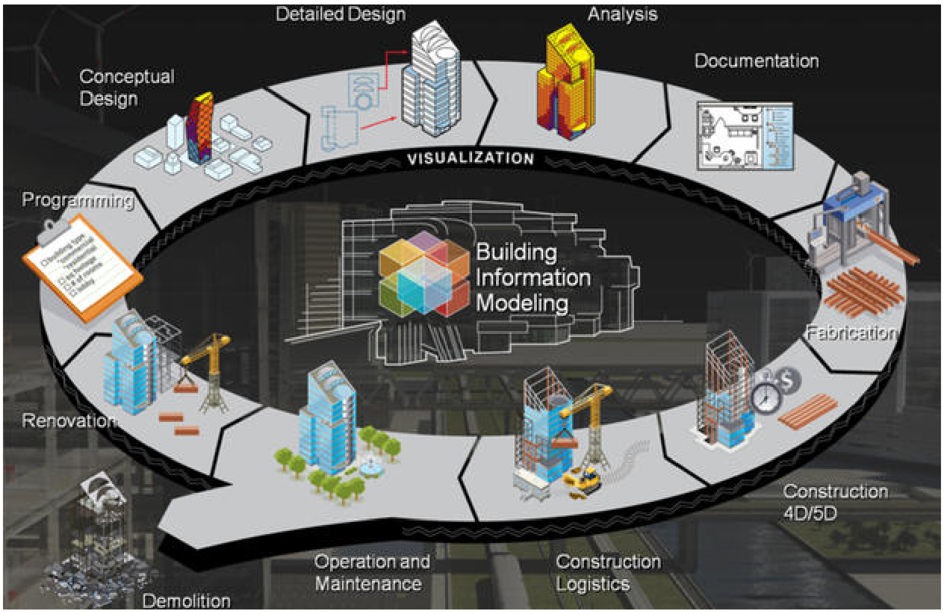

Figure 2.1: Building lifecycle. [15]

Well implemented BIM is supposed to cover all phases of building lifecycle, from first design sketch until demolition or reconstruction of building see:2.1 .

This chapter is mainly based on information from [13] and [16].

2.1 BIM in Czech republic

In September 2017 Czech government under the prime minister Sobotka approved into practice conception of BIM implementation in Czech Republic. The most important statement of this document is:

"Implementation of BIM methodology will save expenses for construction, administration and reconstruction of buildings and structures. Thanks to implementa-

tion of BIM methodology in non-digitalised construction industry, will state, as good treasurer, for same amount of money be able to create and maintain more constructions than up to now."

BIM implementation is not only topic in Czech Republic, it is broadly discussed in Europe. In Europe we can clearly see trend in BIM implementation mainly in wester parts of Europe. Reasons are quite clear - in highly developed economies need industries with lower level of digitalisation to follow the progress. This is also supported by lack of workforce for low payed construction positions. However in eastern countries, we still see no motivation for implementing BIM.

This recommendation published by Ministry of Industry and Trade quite clearly outlines the strategy for BMI methodology implementation for next 15 years. From year 2021, all public constructions are required to have correctly created BIM model. This is bound to spark quite a big discussion because there is no norm covering "correct" definition of BIM model currently.

Czech approach for construction digitalisation is little bit different from western countries, where main motivation for BIM implementation are tax refunds and simplified construction permission process. Here, in Czechia, Ministry of industry and trade is supporting digitalisation of construction industry by government and public quotations. State is therefore coordinator of BIM implementation, private sector is offered methodology and budget to implement BIM in their own projects.

One of the big topics for government BIM implementation is combination of BIM data and GIS (Geographic information system). Together with digitalisation of land registry, it is the biggest challenge to enter fully digitalised construction engineering.

Figure 2.2: Building information model with underlying GIS data. [17]

Complete description of BIM implementation methodology is covered by government concept in [18].

2.2 Building information modelling as tool for reduce costs

As mentioned at beginning of this chapter, BIM is becoming world trend for preparation, managing, and sustaining constructions of all types. Behind this revolution are, as always, budget cuts that we are able to make. Thanks to this integral approach.

2.2.1 Budget justification for BIM implementation

Correct implementation of BIM is followed by increase of efficiency and transparency over all project phases. Right at the beginning, it is important to say that BIM is good servant but terrible master. Some phases are practically impossible to complete without correct BIM but sometimes it can happened that wrongly implemented BIM is only for worst.

Transparency BIM is bringing full transparency to the project documentation and, if all involved subjects are using BIM, to project time schedule. BIM tools are capable of automated generation of project documentation, automated import of project changes, and keeping all alternations from project documentation tracked. It basically automates construction supervision and supply site manager with real time relevant information. Increase of transparency could be understood negatively by designers or site managers. However biggest benefit from transparent solution gets investor, who has full insight into project quality, schedule, and costs.

Efficiency From the point of increase productivity, BIM is bringing full toolbox of possibilities to raise productivity during first phases of building design and construction as well as during usage of building itself. During design phase, it helps speed up decision process for final project. Thanks to extensive possibilities of automated generation and automated check of construction modification. It helps all involved parties - architect, technology engineers, and investors to agreed on those modifications swiftly and effectively.

During construction phase, thanks to possibilities of todays hand-held devices, it allows construction workers and site managers to review, understand, and solve all obstacles that modern constructions are bringing. It is easier to understand positions of pipes, wiring, and structural beams on 3D model rather than on paper. Site manager is able to report all delays and phases of construction into system software than decides which parts of construction are effective to be build next. This computer generated schedule is bringing some demands on site manager to be able to work with the system and to understand its processes and follow its recommendations.

Main advantage of BIM usage for project is early correction of mistakes. During the whole lifecycle error cost is escalating. During the operations, cost for error fixing could be 20 times higher than during design phase 2.3 . BIM could help solve this.

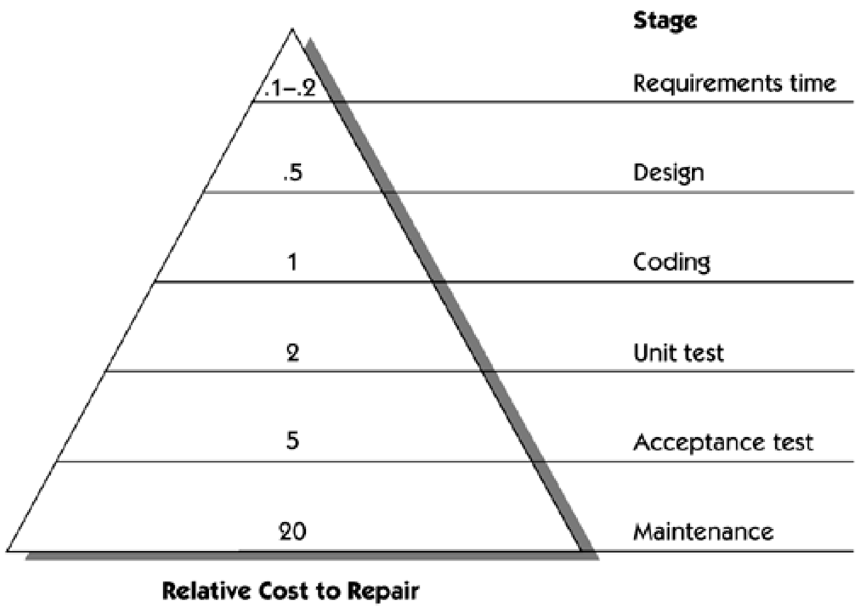

Figure 2.3: Rising of error fixing in lifecycle. [19]

2.3 Modern approach to building information modelling

Concept of building information modelling was first mentioned in Mid 70s by Charles Eastman from Carnegie-Mellon University in Pittsburg in paper *An Outline of the Building Description System.* It took more than 40 years for big business players to recognise its advantages and implement BIM into computer construction systems. Building information modelling, as big topic, appears in last 5 years. First projects correctly implemented in BIM are starting to appears now. Therefore there are plenty of new and quite interesting topic to cover in cooperation of BIM with manufacturing industry. In following lines, I am going to mention some new approaches and findings that BIM brings to the industry. I believe that can help us, in Testbed to dig deep into this topic.

2.3.1 Knowledge based BIM

Usually, developing BIM starts with 3D CAD and implementing information into this model. Knowledge based BIM is designed not only to store and provide construction relevant information, but also to work with processes and procedures that responsible personnel developed for construction and operations of building.

Design expertise True quality of building is often recognise by level of solved details. To be able to see, solve, and implement detailed solutions, engineers and architects have spend years of practice to develop their design expertise. Each one of them has to develop his own design heuristic and transfer this knowledge is often based on one-to-one sessions, if even so. Often, valuable knowledge is lost when top tier experts leave the field or pass away. BIM is able to help here in two different ways:

First, it can store and put into context comments and decisions made by field experts. These knowledges are stored permanently with building model. If those comments are written and documented responsibly, it becomes vast library of design expertise from multiple experts in different fields.

Building design expertise with Knowledge based BIM Second, knowledge based BIM can help non-expert designers to build and implement advanced design features. Traditional BIM is full of useful and semantically rich information. We can mine this information and use it for better design and to build design expertise. I have implemented and used knowledge based BIM in example 5.1 implemented in CIIRC building. In this chapter I have described full potential and process of implementation.

2.3.2 Simulation and analysis of buildings with BIM

Since 1970s when BIM as a concept was first presented, all capabilities of building information modelling were held back by lack of computational power. In last 10 years, prices of powerful HW and accessibility of SW tool enabled creation of so called "digital twins" - behaviourally dynamic, three dimensional prototypes of building and machines. Lot of following procedures are shared between manufacturing/OEM (Original equipment manufacturing) and AEC (Architecture, engineering , construction) business. Simulations based on digital twins are becoming standard for all industry and construction. So we can benefit from both.

In this section, I will no be talking about topic of simulation physical and structural behaviour of constructions, that is covered in section 5.1. Main focus is on energy and thermal behaviour simulations.

Conceptual analyst Possibility of energy analyse of BIM model came with evolution of BIM model into second generation BIM 2.0. This generation brings three main advantages:

1. multidisciplinary - integration of more detailed BIM

2. complex geometry in skeleton as well as inside structure

3. fixed items (windows, doors) as well as condition driven parameters (wind, temperature, vibrations, etc.)

All those three evolutionary steps are helping to create more complex and holistic digital twin of building above which we can run simulations with sufficient precision.

Softwares for detailed simulations are enabling manual change of parameters, such as positioning of windows, as well as automated condition testing - like a year round temperature variation. All results from those simulations can be stored in BIM and be used during building operations for whole lifecycle.

Building performance simulations Energy modelling is supposed to be implemented from the beginning as part of design process. This approach is not only driven by business potential but also by sustainable approach and energy efficient buildings. Today most advanced software are the ones used by energy consultants and connecting BIM with them is quite complex. BEM (Building energy modelling) is part of BPS and it is supposed to simulate energy flow through building during operations. Proper use of BEM can help predict building behaviour during occupancy and in helps cut costs for maintenance, additional modifications and operation energy. Because of complexity of full BEM implementation, it is vital to set up several keystones during design and check building performance only in those keystones.

BIM role in BEM is to offer needed data for simulation. Than, precision and feasibility of simulation depends on quality of supply data from BIM. Thus, it is really important to have correct information about premises we are going to simulate. Proper materials, shapes, volumes etc. Also we need all performative aspects of building such as occupancy, set temperature, light conditions or electronics inside rooms. Topic covering energy and thermal flow in Testbed are covered in chapter 5.1.

3. Industry 4.0

Fourth industrial revolution is symbolised by increase of data flow thru production and higher involvement of ICT technology into manufacturing process [20]. This requires high standardisation of data formats, description of processes and overall efficient manufacturing management. Currently there are several architecture models which are designed to support those requirements. Each model has been developed with respect to its point of origin. In Testbed, we have decided to use model RAMI 4.0, main reason is our link to German economy and Czech Government Initiative for Industry 4.0 [4].

3.1 Standardisation

For full implementation of Industry 4.0 idea of self-managed production machines and processes, standardised communication, and open description of manufacturing tools is necessary, so all parts of chain can be connected into one system. From currently used standards, there are ISA-88 batch control and ISA-95 as enterprise-control systems integration standard. As well as for manufacturing standards, there are standards used for programming and communication on field level and in vertical integration, IEC 61131 as standard for PLC control devices and PLCopen for programming. Communication is mainly based on OPC-UA and field buses, in case of Testbed on PROFINET. Two main standards, important for manufacturing industry in Europe and America regions are RAMI 4.0 and IIRA.

3.1.1 RAMI 4.0

Reference architectural model for Industry 4.0 (RAMI 4.0) was developed by German based subjects BITKOM, VDMA and ZVEI. It describes every enterprise on 3D model. RAMI 4.0 connects all aspect of manufacturing into one space, where all information is stored, no information is doubled, and accessing all aspects of model is standardised and transparent. Visualisation of RAMI 4.0 model is on 3.1. Deep description of model is given in [6] implementation manual.

All components involved in manufacturing process, have to be covered in model by sufficient quality of data, not only by information and communication representation, as for mechanical parts by its drawings and dimensions.

Vertical layers have to be be able to cooperate with each other. We can go only layer by layer, not jumping diagonally in the model. From top to bottom we can go deep down from overall description of business into single sensor and see all its links.

- Business layer: In business layer, we can find description of business model and different business processes with its connections. Also we can find legal and regulatory frameworks.
- Functional layer: There are stored formal descriptions of functions. We are representing here runtime and modelling environment for services from

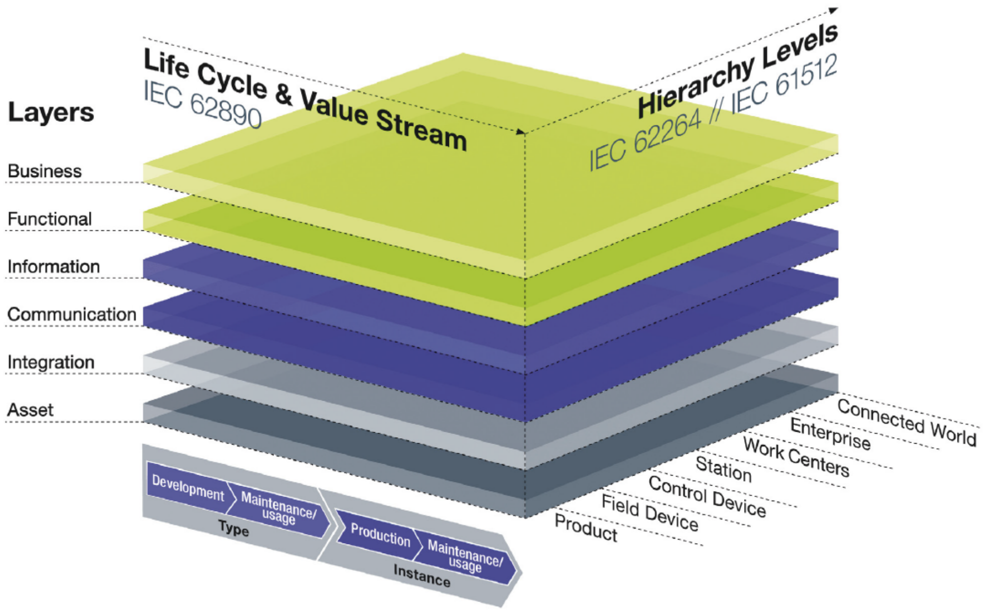

Figure 3.1: Visualisation of RAMI 4.0. [6]

business layer, but also applications from lower levels. Decision making is integrated into function layer as well as remote access.

- Information layer: Event preprocessing and execution. Description of time and event related rules. Because this layer if full of legacy data and processes, here is most complicated part of overall integrity of model. Description of manufacturing line in AML 4.4.3 is located here.

- Communication layer: Is providing resources for data transfer in model. OPC-UA information model and PROFINET addresses are in this layer.

- Integration layer: Contains all the HW that controls and runs the plant. Here is implemented interaction with humans and connected IT.

- Asset layer: Is representation of reality, physical world with parts, diagrams and manuals. Here we store as well humans ;) and getting passive connection to higher level (QR codes, tags,...).

Life Cycle and Value Stream In Industry 4.0 thanks to unified data stream, we are able to share data in both directions. Which means not only to create and manufacture the product based on given description, but also close the feedback loop and improve product and production based on real life data coming back in lifecycle. For this axis of model, IEC 62890 norm about Life-cycle management for systems and products used in industrial-process measurement, control and automation is used as a draft. It is used as guideline for whole lifecycle of product, production and services.

Basic idea is, difference between type and instance:

- Type: Creating type is first step of lifecycle, it comes with product concept, development and later with testing and prototyping of product. In this phase, we do not create only products but also production machines and lines. At the end of this step, type is released into production.

- Instance: Manufacturing of product or machines is based on its type. Each produced product is than instance of type. We can identify each instance by its unique symbol (serial number) and trace it back to its type and production process. When customer receive our product as instance, for him, it is again only type until he uses it. So change from type to instance could happen several times. Types are optimised based on data coming from usage of instances.

For better understanding on 3.2, you can see comparison of lifecycle from RAMI 4.0 with standard life-cycle norm.

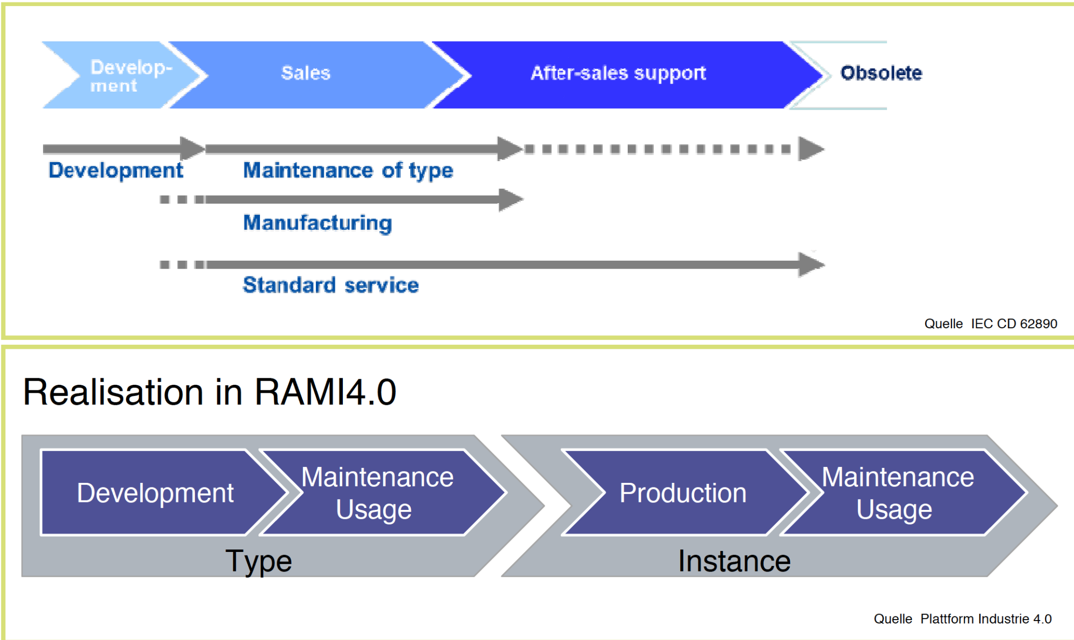

Figure 3.2: On top, is visualisation of lifecycle according to IEC CD 62890, on bottom according to RAMI 4.0 [6]

Hierarchy levels Last axis on cube describes level of functional classification of certain object in model. In past hierarchy was understand as pyramid based on field devices up to MES or ERP systems 3.3 this is defined by IEC 62264 and 61512 standards. In industry 4.0, as matter of fact, RAMI 4.0. We have to involve in this hierarchy all layers, this is creating some confusion in public, hierarchy levels are not represented only by physical object, but also by digital.

New understanding of hierarchy complies with IEC 62264/61512 inside the shop floor, but RAMI 4.0 also implements layer of products at the bottom of hierarchy. Also top level includes groups of factories and collaboration with external suppliers, engineering firms for big data integration, automatic streaming of data and orders to and from the connected world are added. Full insight into the hierarchy is on 3.5. This allows for creation of unified model of collaboration between multiple enterprises.

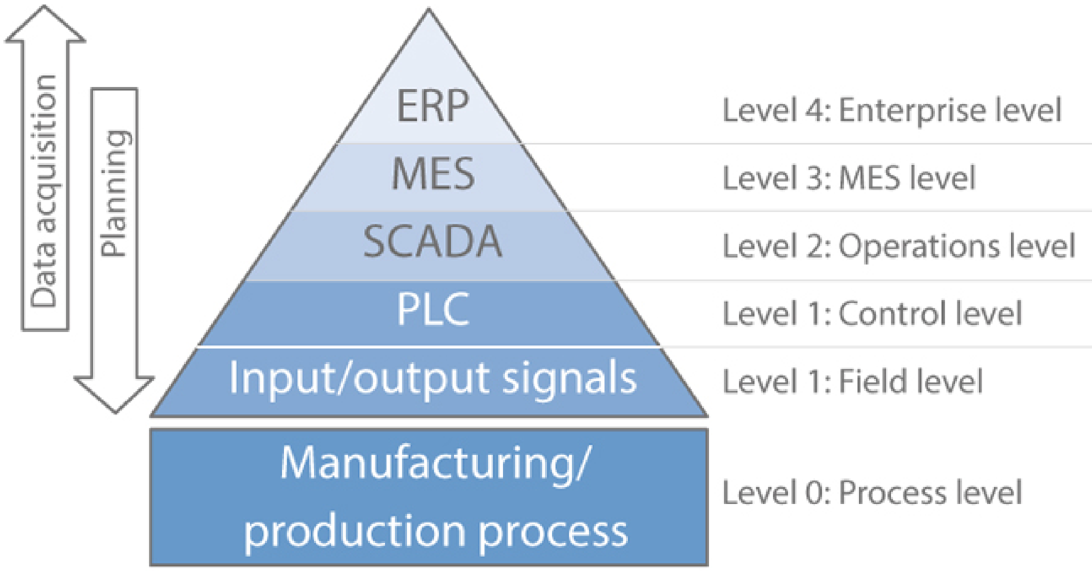

Figure 3.3: Hierarchy of manufacturing plant in industry 3.0 understanding [Platform industrie 4.0]

3.1.2 IIRA

IIRA is model developed by Industrial Internet Consortium. It is build specifically for the use of internet in industrial purposes. It is focused more on communication point rather than on product lifecycle as RAMI 4.0. It is more suitable for other than manufacturing enterprises such as health care, smart-city or transportation. More information is in freely accessible document:[21]. In our scope is only communication gateway between models. It is likely that after future development Testbed will be connected to the broad systems of smart services. These services will be build with respect to IIRA model architecture, according to current situation. We can see similarities of IIRA and RAMI 4.0 when we open IIRA model in functional domain perspective 2.1

3.1.3 Harmonisation of IIRA and RAMI 4.0

Because of trend in system integration of all new "smart" activities, there is a need for unified gateways between models. Since the agreement between European Platform for Industrie 4.0 and US Consorcium for industrial internet from March 2016, IIRA and RAMI 4.0 are easily connected and prepared to work side by side. Basic functional mapping of models is shown on 3.6 and described in document [22].

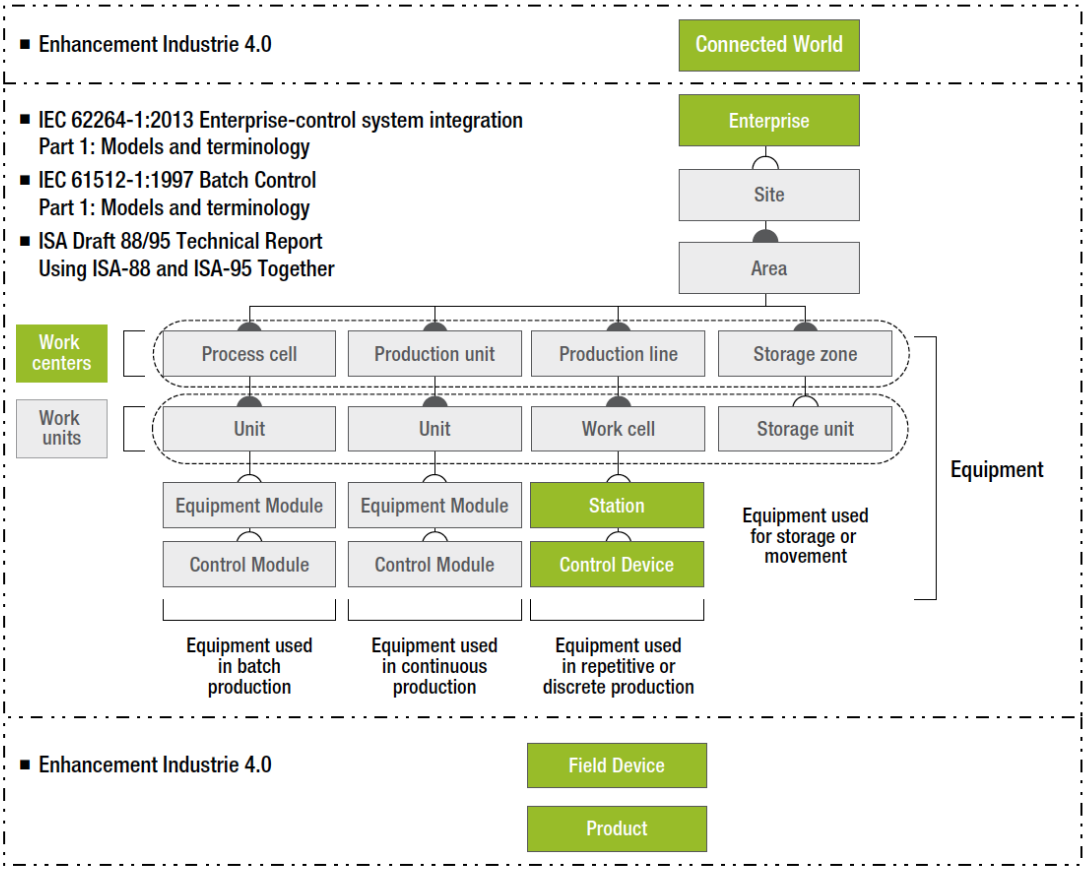

Figure 3.4: Derivation of full hierarchy inside RAMI 4.0 [6]

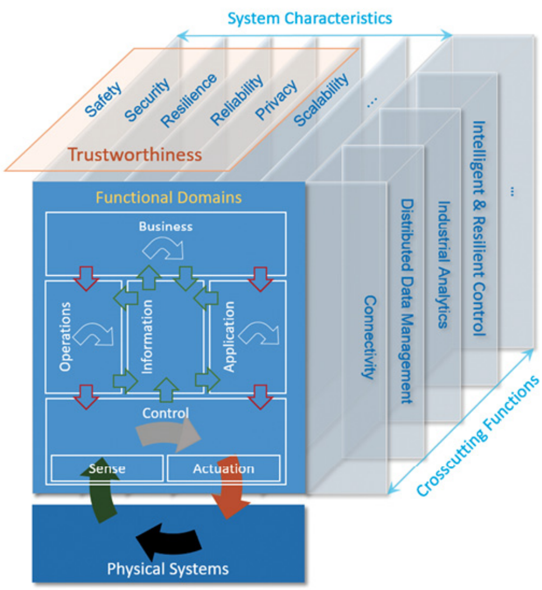

Figure 3.5: IIRA model with view in functional domain. [21]

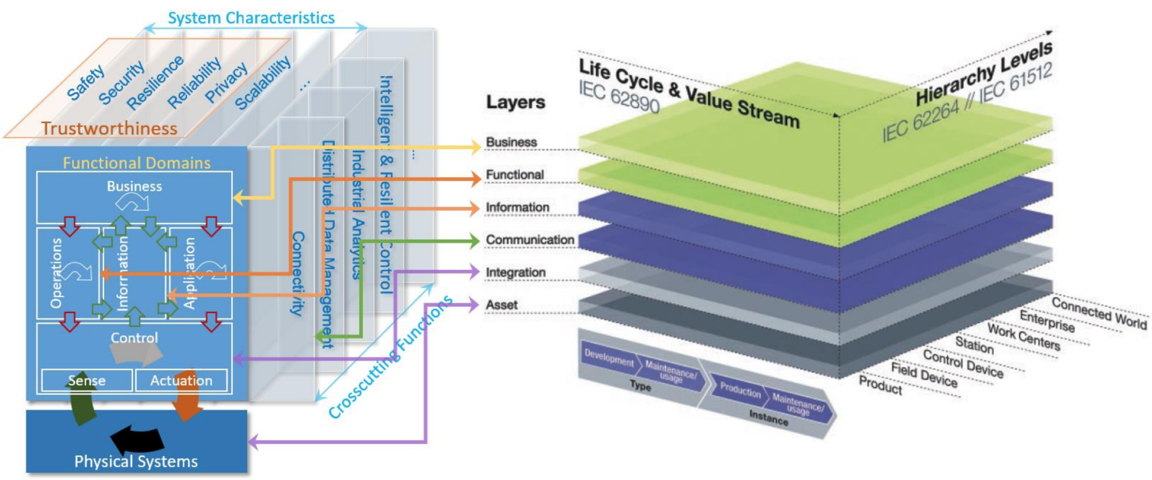

Figure 3.6: Functional mapping of IIRA and RAMI 4.0 models. [22]

4. Implementation of RAMI 4.0 on Testbed

Testbed, as fully integrated digital enterprise, is supposed to be integrated into RAMI 4.0. This enables transparency and better understanding of all processes happening on shop floor - as well as mapping of information flows thru production. Because of high complexity of so far developed system, I am going to cover mainly the manufacturing and shop floor energy measurement system integration ratter than business processes layer.

4.1 Object to Industrie 4.0 component

All parts of Testbed could be referred to as objects. To become fully implemented Industry 4.0 component, we have to encase them in so called administration shell. This shell is describing technical functionality of object and its virtual representation. Graphical representation is on 4.1.

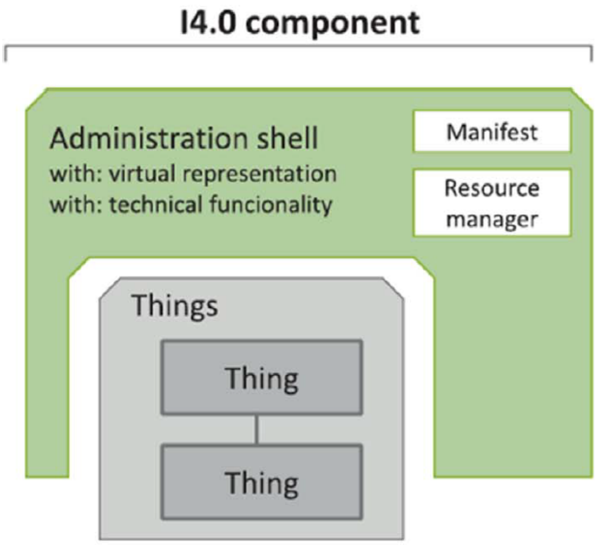

Figure 4.1: Object enclosed in administration shell representing its functionality and virtual representation. [6]

Administration shell unites all data generated in lifecycle [23]. This means not only production data, but also data from prototyping and utilisation. In language of RAMI data from phase of type and instance. Properties could be:

1. Basic - name, ID number, CAx data, ...
2. Mandatory - communication interface, information model, description in AML
3. Optional
4. Free

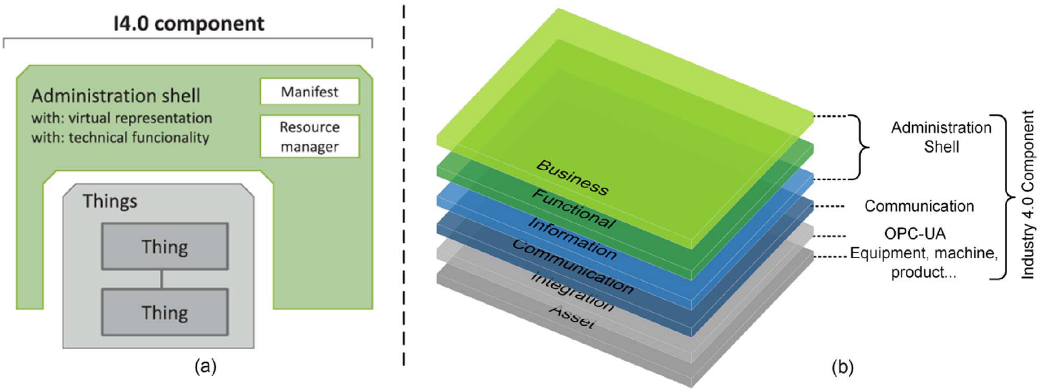

Figure 4.2: Component representation according to RAMI 4.0 and linkage of component to layers [20]

Thanks to those properties, we are able to implement concept of plug'n'produce model. We can set "envelope" or "margins" of possible variations of properties for every component to be able to communicate within production and be able to implement new component into running system structure. Each component consists of several submodules and communicates with them using standardised interface in administration layer 4.3. As a description of object, I have used AutomationML 4.4.3 and description can be see on 5.7. As interface for administration shell is used OPC-UA with unified information model see 5.8.

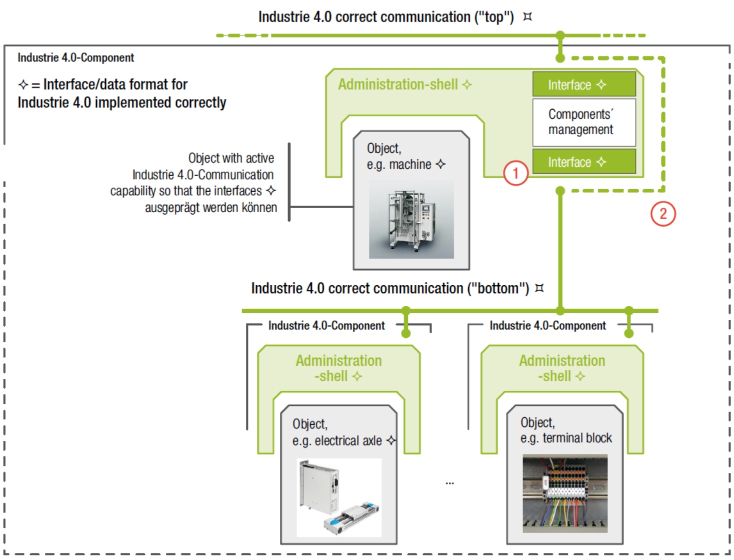

Figure 4.3: Representation of several assets on shop floor. [6]

4.2 Using data from BIM in RAMI 4.0

BIM data are a useful part of administration shell of Industry 4.0 component. Proper BIM model inherits information regarding size, temperature properties and state of building services. We can use those data as envelope/margins for administration shell properties by means of maximal size, weight or temperature gains of technology located in rooms or supply electricity. As well as data from administration shell can help during building operation and modelling or in phases of demolition/repurposing of construction.

Possible used data:

- Geometrical properties - maximal sizes of technology, weight, loads per square meter, working space of robots.
- Thermal simulation properties - maximal thermal gain of integrated systems, ambient temperature of installed technology, volumetric control during manufacturing process
- Electrical consumption simulation properties - maximal load of main power supply of building, process design with respect to quarter hour maximums.

4.3 Testbed assets in RAMI 4.0

Assets of testbed could be in physical or virtual world [24] . All assets are located in bottom layer of RAMI model, the asset layer. Some assets are interconnected to other layers based on its purposes. All testbed line components are located in instance part of life cycle, only product sketches or currently developing new work stations could be part of type group.

Combination of asset and administration shell creates component. In following lines I am describing possible information stored in shell, assigned to components of testbed. In 4.4 is deeply concluded how RAMI works in process of energy measurement.

4.3.1 Production line

Production line consist of combination of several transportation devices (shuttle system, robots) and three control cabinets, where electronics and automated storage unit is located 4.4 . Line is well mirrored assembly line for automotive industry and it complies with Industry 4.0 demands for flexibility, effectivity and plant dynamics.

Location of line in RAMI model is in level of asset layer and on work centres hierarchy level. We have to understand that administration shell is not one. For each life cycle stream step, object has different administration shell 4.5. Line is implemented by system integrator but designed by onsite staff. That is creating multiple administration shells. Every stakeholder has access to only its data in model. Shells have predefined interfaces where they meet and exchange data. For clarification, in testbed those interfaces has been people in personal or mail communication. On 4.5 is graphical representation of different administration shells of production line component. In lifecycle is generated different administration shell for type and for instance:

- Manufacturer
  - *Type* - development documents, certification testing records,...

Figure 4.4: Photo of line, representing and object in industrie 4.0. CVUT 2017

  - *Instance* - information about manufacturing and use of material

- System integrator
  - *Type* - programming manuals, global libraries of functions,...
  - *Instance* - operation manual, project libraries, program itself

- Operator
  - *Type* - ordering process, manufacturing process, BOM, BOR, BOP,...
  - *Instance* - orders, life process data, dispatch notes,...

- Business integrator
  - *Type* - business strategy, pricing, marketing target groups,...
  - *Instance* - economical results, expenses, marketing campaigns, agreements with customers,...

4.4 Example: Energy measurement in RAMI 4.0 modelling

In this section, I am using mentioned modelling methods and describing representation of energy measurement system implemented in Project 2 [9] on line with respect to RAMI model.

4.4.1 Measuring device

As measuring device, it is implemented analog input card AI Energy Meter 480V AC ST MLFB(Maschinenlesbare Fabrikatebezeichnung - manufacturing number): 6ES7134-6PA20-0BD0. We are measuring several electric properties: voltage,

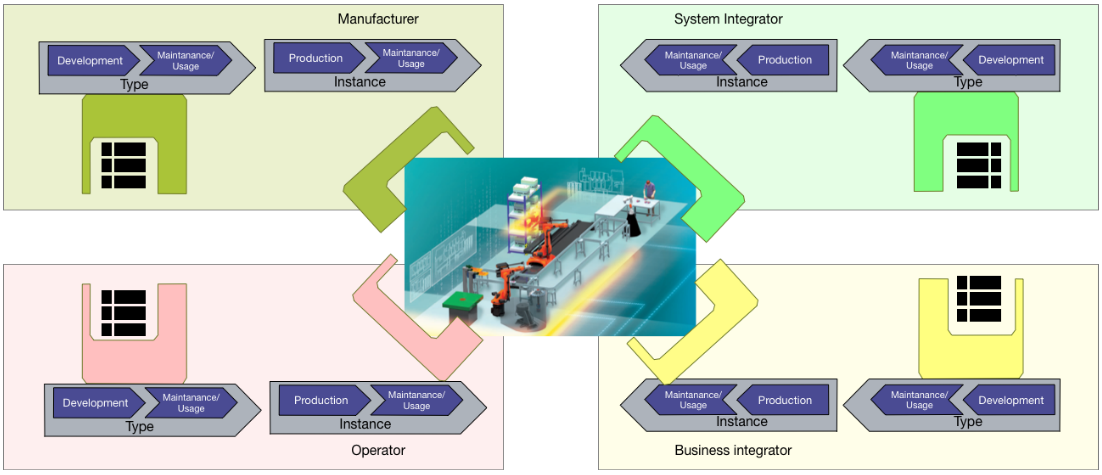

Figure 4.5: Multiple representation of administration shell from perspective of different stakeholders. Quelle: Author

current, power, active power and energy. Connection to card is realised according to 4.6. There are three measuring points for 3-phase measurement by 4-wire connection. For measuring current current transformer is used with ration 100/5A MLFB: 3NJ6920-3BD21. For measuring power supply to IIWA robot, 1-phase 2 wire measurement is used. All connections are well documented in control cabined documentation.

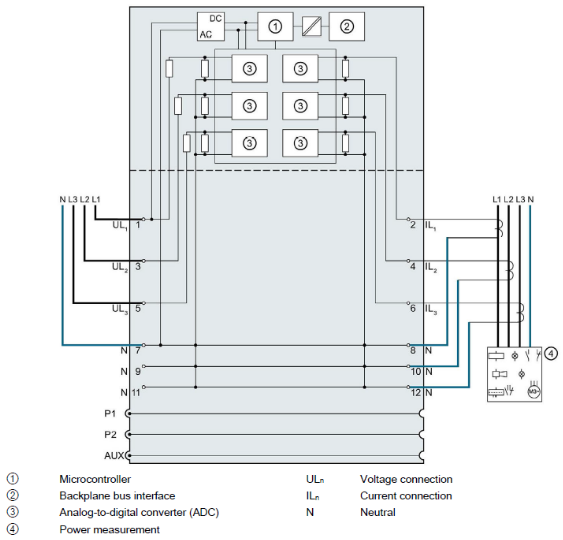

Figure 4.6: Connection to analog input card for energy measurement. Quelle: Siemens AG

Measuring card is connected to base unit of decentralized peripheral ET200SP with inner system bus. ET200SP decentalized unit is using Profinet communication and streaming data to central line CPU PLC S7-1518PN/DP ODK MLFB: 6ES7518-4AP00-3AB0. In PLC is created energy measurement program using TIA portal option Energy suit V15. Every measurement device is defined as energy object in energy object table, that allows to use automated code generation. Program for energy measurement is automatically generated and values from measurement cards are stored in data blocks in PLC program.

4.4.2 Energy data evaluation

Data about energy consumption are stored inside PLC on integrated memory card in form of .csv file. Real time values are accessible thru HMI panel used to control production on line on main control cabinet. On HMI, we are able to access 60 minutes historical data, this information could be used for maintenance purposes and for quick localisation of possible error. In testbed is installed Simatic energy manager PRO, it is company wide energy management system. It is build to comply EN 50001 and as open system with possible multiple sources of measured data. More information about energy manager PRO are in [9]. Last, but not least, as data evaluation tool is used cloud system Mindsphere. In this cloud operating system is implemented energy efficiency app that gathering data about energy consumed over time and over operations. We can therefore say, if our efficiency is growing or if there is any problem.

4.4.3 Integration in RAMI 4.0

We will start with description of involved tools in measuring chain and placing them in RAMI model environment. Each tool or object got its own administration shell, if it cannot hold data by its own, its got "external" shell and data are hold in nearest superior object. Data are shared by means of OPC-UA and represented in AutomationML. On life cycle axis we are in instance part because complete measuring chain is in production. Evaluation tools got overview into maintenance part. See 3.2.

AutomationML or Automation Markup Language is open standard for description technology and processes in automation projects. It was released in 2009 in cooperation of several automation companies and initiated by Daimler as part of Digital Factory initiative in 2006. It is suppose to be universal communication tool between programs of different origins and manufactures. It is defined by norm IEC 62714, more information can be found on www.automationml.org.

4.4.4 Measuting hardware in RAMI 4.0

As mentioned before we are in production step of instance of life cycle axis. Now we will describe from bottom lever all required components for getting energy data as information into PLC.

Measuring transformer is located in asset layer in field device level, it is lowest component in this task. It transforms energy from energy source cables into lower current recorded by energy measurement card. Its administration layer is located in PLC and on web server of manufacturer. We can access them with QR code located on device or thru PLC code in DataBlock where those information are stored. It has overlap into integration layer where is located connection of transformer into measuring card.

AI energy meter 480VAC ST is card, which transforming voltage and current measured by measuring transformer into information about energy, power, etc. It is located again in asset layer on field device level. It has direct connection onto power cables to measure voltage. In integration layer it has connection to base unit of distributed peripheral. **Base unit of distributed peripheral** is located again in asset layer on field device level. But in difference from transformer and card it has instance in communication layer. There is located PROFINET communication protocol which is used to transfer data to the PLC.

CPU Simatic S7-1518 is main PLC of the line. It has HW representation in asset layer, but now we are in control device level. It is used as central point for communication and managing manufacturing tasks. It has multilayer representation from asset up to functional layer. There is description of layers:

Asset layer is holding hardware itself. There is located CPU and all the text and identification marked on CPU.

Integration layer is creating connection between real and digital world. As well as inner communication inside CPU and its components. There are specified protocols and connection between digital twin and real hardware part.

Communication layer is responsible to connecting different asset object together, there is PROFINET and OPC-UA communication specification. If we want to move data between objects, we have to always go thru communication layer.

Information layer is holding all information regarding manufacturing process (BOM, BOP, BOR), it requests them from Teamcenter. It is holding information about object itself, how it is enrolled into testbed network.

Functional layer is holding formal description of functions running on CPU and getting data in information layer into context. Here we create connection between energy consumption and production process.

From description, it is obvious, that CPU is our centre point of getting energy data. It process them, evaluate, share and store.

4.4.5 Evaluation of energy data in RAMI 4.0

For evaluation of energy data, we are using three different systems see [9] . Each of them has different timeframe and slightly different purpose.

1. **Direct visualisation of current energy data** is based on CPU and HMI panel installed in door of main control cabinet. This visualisation process is located in asset and integration layer, only data streaming is go up into communication and back into integration layer. Whole process in on 4.7. Image is simplified for better understanding. We are only in bottom levels of hierarchy and in instance of lifecycle. Red arrow is following process of direct reading of energy data and storing them in CPU. Orange arrow is following process of visualisation data on HMI panel.

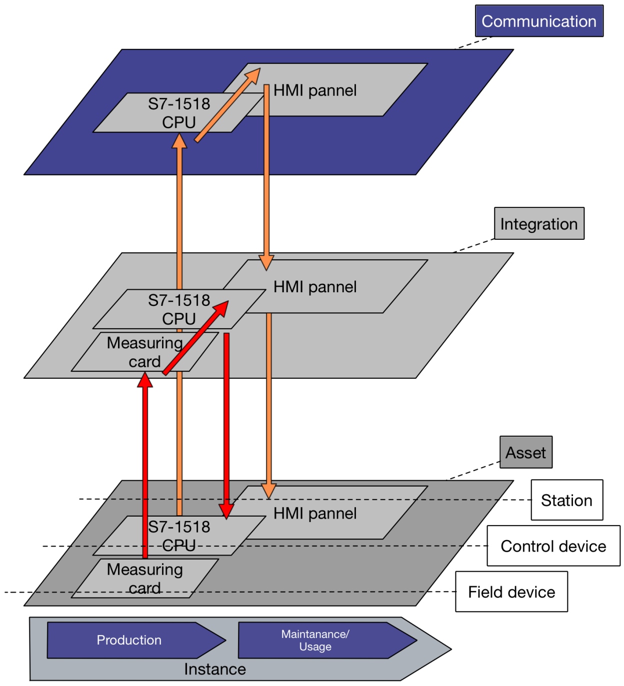

Figure 4.7: Direct energy visualisation of station data in RAMI 4.0, Quelle: Author

2. **Evaluation of energy data with Energy manager PRO** is used as energy evaluation tool in conformity with ISO 50001 and ISO 50006. It produces dashboard and reports regarding energy use and stores data for long therm statistics and analytics. In testbed premises, data are gathered only by automated system from main CPU and four energy measurement points. All those processes are managed in local network and hardware located in testbed. There for, we are located up to enterprise level of hierarchy but in all layers from asset up to business. In lifecycle, we are again only in instance part. On 4.8 is overview of two processes running on Energy Manager PRO. Red arrows shoving process of collecting data from main CPU into EnManPRO system and creating dashboard for line operator and maintenance crew. Orange arrow is showing process of evaluation energy dashboard and improving process according to ISO 50001 on management level. In downward stream is process of storing information about energy used for production in dispatch note of manufactured product.

3. **Performance analytics with cloud system Mindshere** is last mean of analytics of energy data. In Mindsphere cloud system is running app that is evaluating energy data in context with manufacturing process. On 4.10 is preview of app. On 4.9 is visualisation of process of storing data into cloud, follow red arrow. Process of feedback improvement of manufacturing process is implied by orange arrow. Feedback is on two places. First, on business layer, where has to happen business decision for energy saving and process optimisation. There, data that suppose to be optimised are transferred to development environment the TIA portal. Now optimisation of PLC/CPU code is happening in Type section of Lifecycle. Second feedback loop is in functional layer, where is tested optimised program on digital

twin of process and PLC/CPU. If it is comply with all requirements, than it is loaded into production HW down to asset layer.

4.4.6 Program changes for energy transparency

In order to make manufacturing process fully transparent, there are some needed changes in main CPU. Currently, we know only about type of operation that is being processed on manufactured product. In order to make fully completed dispatch note, we need more information.

- Time stamp - we need to add timestamp to beginning and end of operation. Lower in levels, better. Currently, we know timestamps from Abra ERP system. For precise statistics it is not enough. Therefore, we has to implement timestamps into beginning and end of every manufacturing operation.
- Energy per operation - As well as time, we has to implement energy counter in every operation and collect its data into dispatch note. This will give us transparent insight in manufacturing process.

Unfortunately, because of hight complexity of PLC program, I have not been able to implement all those changes. It has to be performed with system integrator in next optimisation of PLC program.

4.4.7 OPC-UA structure for energy measurement

I have described structure for energy measurement in AutomationML 4.4.3 than implemented in OPC-UA as interface to data block holding information required for fully "RAMI capable" model. Structure is divided by standard of this language and imported as OPC-UA structure into CPU via TIA portal. Description of OPC-UA interface is in part 5.2.4.

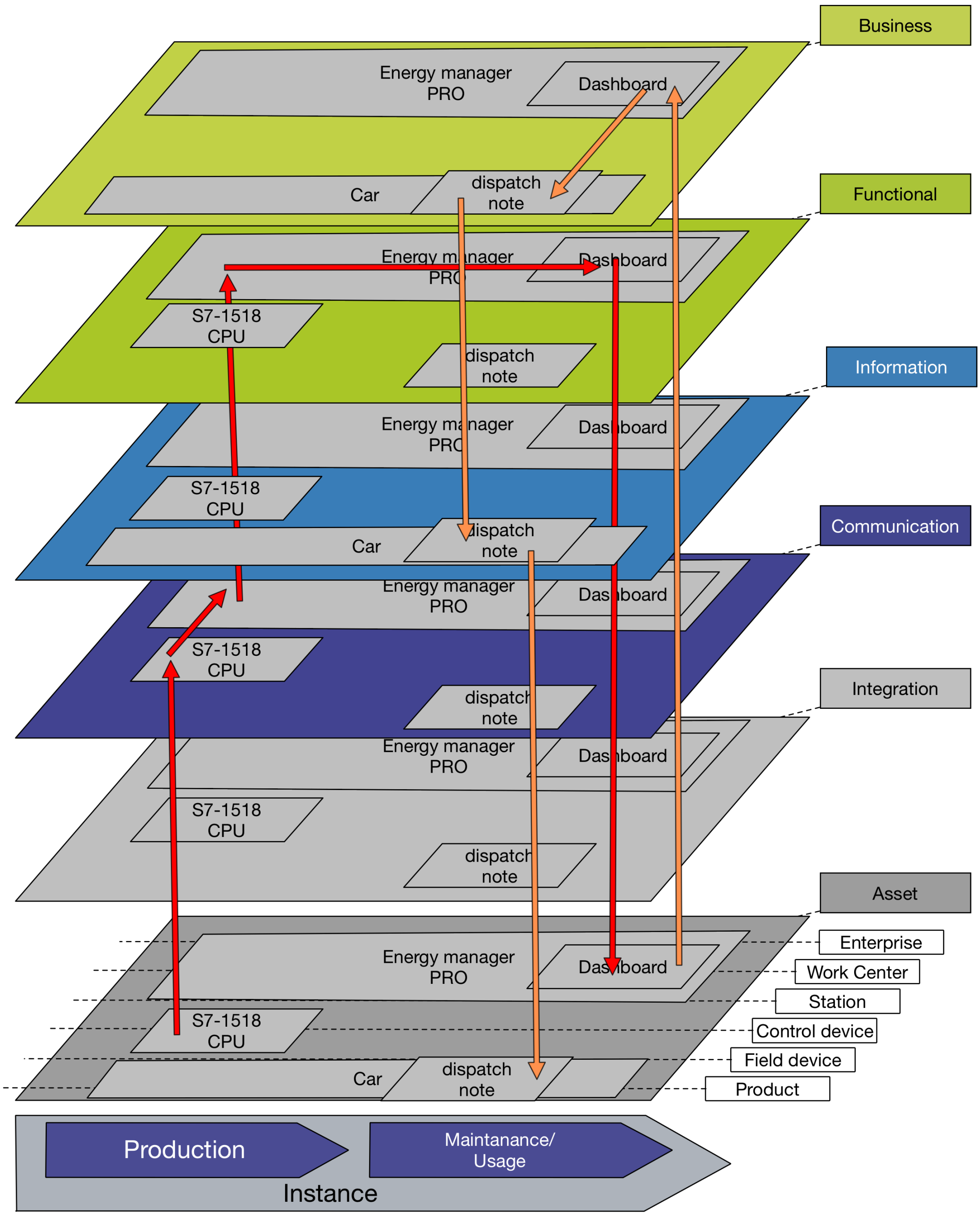

Figure 4.8: Energy management system process overview in RAMI 4.0, Quelle: Author

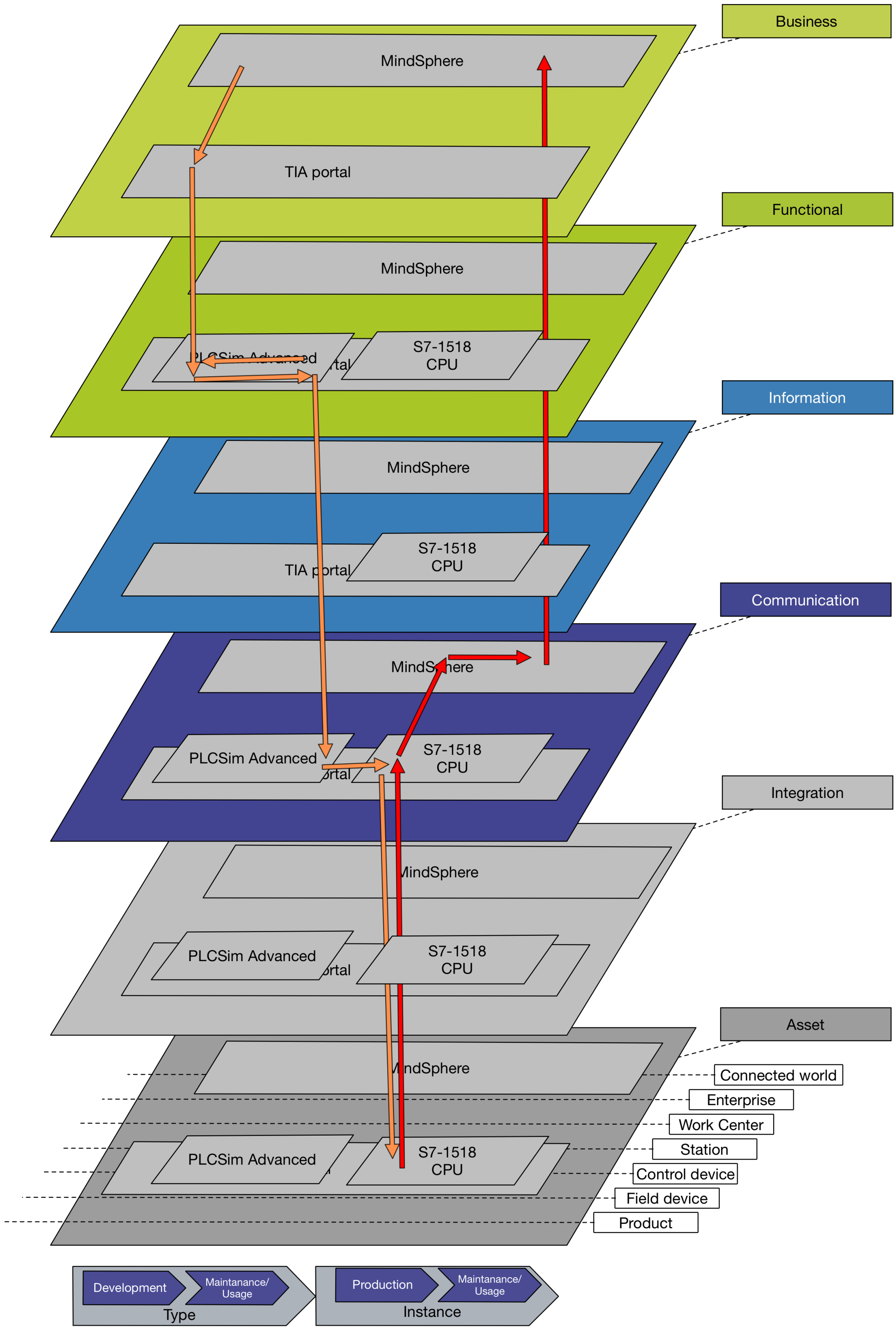

Figure 4.9: Integration of cloud analytics (red) and process optimisation (orange) into RAMI 4.0, Quelle: Author

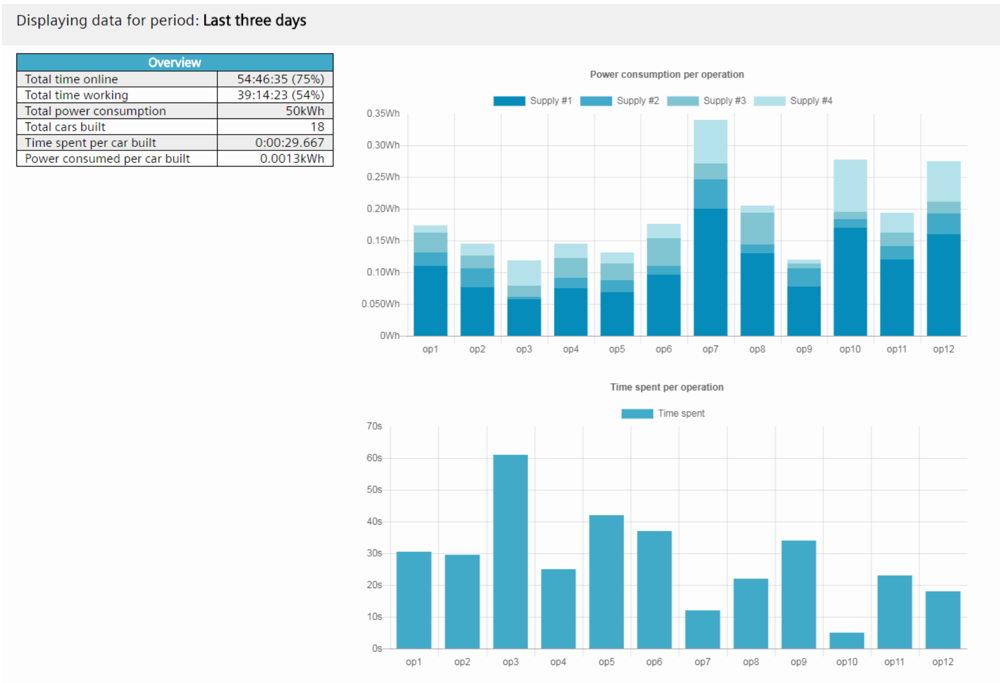

Figure 4.10: Energy evaluation dashboard in Mindsphere, Quelle: Author

5. Implementation of building to line connection

5.1 Energy and thermal flow simulation

In modern manufacturing is growing need for highly precise disruptive and additive manufacturing. With those needs, we have to make precise climate control and assure temperature stability in production premises. That means well designed ventilation and all over HVAC control. We are able to get data from machines about production cycle and high energy gain operation thanks to building-production gateways, one of them is used in 5.2. But high performance HVAC cannot solve those need alone. Therefore, I have created temperature energy model of Testbed premises, it can as well be used to predict not only production but as well conference and presentation because we can simulate gain of temperature not only from machines but from people as well.

5.1.1 BIM model of Testbed

To create thermal and energy model of testbed, I have used BEM software DesignBuilder. For well created model, I have collected necessary energy data thanks to implementation of energy measurement for about a 6 month now. Those data, CAD, electrical equipment and HVAC information packages, are similar that can be used to create full BIM. I will not be creating full BIM, I have lack of software tool to create it and according to my information, there's suppose to be one model already done. My model is "lightweight" BIM with information about space, materials and mainly energy flow. Model can be found in attachments.

5.1.2 Energy flow model creation

In order to create sufficiently precise model in DesignBuilder (DB), I had to convert standard DWG into DXF file and remove several layers of data because DB has problem with loading big external files. In DB I have divided CIIRC building B into several block:

- 1st floor, where testbed itself is located. Visualisation is on 5.1.
  - Testbed - our space of interest, all simulated data are valid only inside those premises
  - Adiabatic Zone 1 - I have defined space around testbed as adiabatic zone, with similar temperature properties as testbed.
- Floors above are specify as standard office building. Floor bellow is specify as wood/metal machining workshop.
- Glass atrium is specify as enclosed space with semi-automated ventilation clamps, because of lack of data, I have used temperature profile predetermined by DB as double layer glass facade.

DesignBuilder is gathering several type of data in order to make precise simulation.

Activity in premises In order to make simulation with gains from human body, activity has to be specify, because human body can produce from 70W to 300W depends on activity. According to my experience and observations, best activity profile for testbed is according to ASHRAE 62.1 - Educational Facilities - Laboratory Science with low intensity work. It is taking into account spasmodic activities in testbed, when once in a time it is filled with people in quite high density and than it is almost unoccupied. As well as it considers people mainly standing up, therefore giving more energy into system.

Density of occupation has been set to 0,2 $people/m^2$. Testbed has area 675 m^2, it means about 135 people in spasmodic occupation. This type of occupation is putting high demands on quality of HVAC control, but we have no possibility of controlling HVAC directly from our system.

In a nutshell, activity simulates conference happening in testbed every day from 10:00 to 17:00 with about 130 attendees and running production line and supporting technology.

Materials and orientation Because we want simulation including solar heat coming thru high testbed windows, model has to be build with respect for orientation and building situated on east side from testbed, in Bubenec behind street Jugoslavskych partyzanu. They are important in blocking some sun in the morning. As well as orientation, important is type of materials of construction. Thanks to complete CAD drawing and BIM model of 5th floor building A, I have been able to set parameters of all construction parts of testbed. Model with orientation can be seen on 5.1.

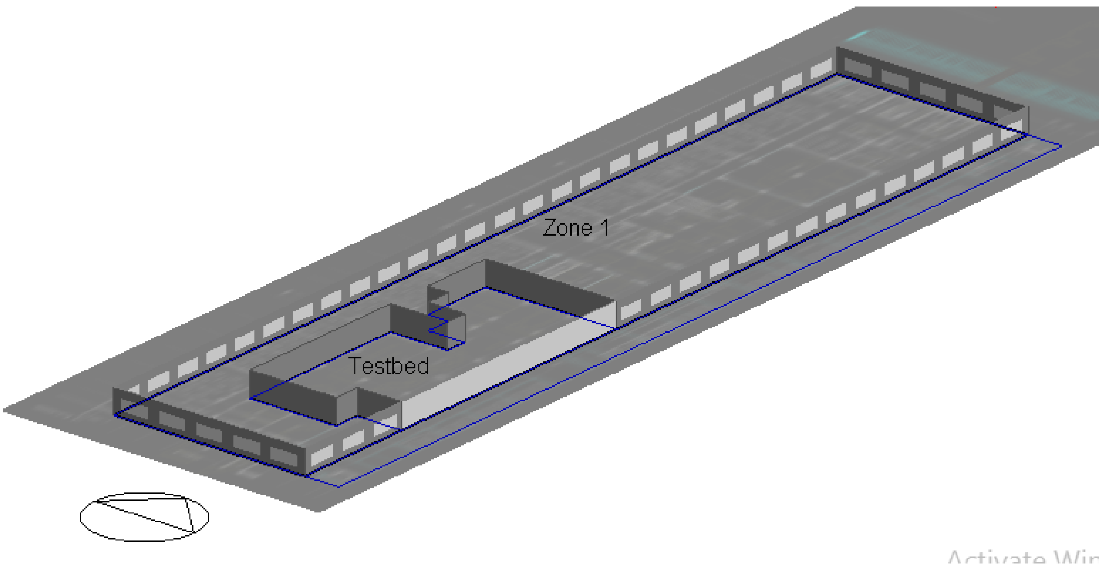

Figure 5.1: Energy flow model visualisation of CIIRC 1st floor with testbed inside. Quelle: Author

5.1.3 Results of energy flow simulation

From model results interpretation, several interesting facts came to light.

Overheating of technology close to the window From heat map on 5.2 we can see, that technology close to the window, about 2m inside room, is getting high levels of solar gains during morning period. In this part of room is located control cabinet for shuttle system Montac, I would recommend to measure and keep eye on inside temperature to prevent defects due to over heating.

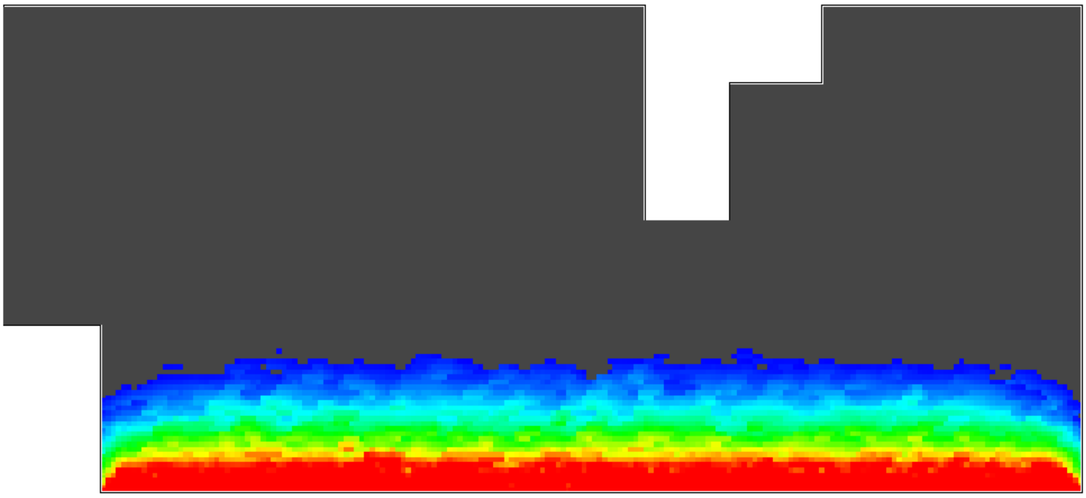

Figure 5.2: Heat map of illuminance of testbed from sun, red is 1000 lx, blue 200 lx. Map is generated for time between 8:00 and 11:00 in 30th of May. Quelle: Author

Morning sun overheating On 5.3 is graph presenting energy gains in testbed. This part is from June to beginning of September. It is clearly showing high energy gains in the morning of testbed premises, this is happening mainly in the end June and beginning of July. Explanation is angle of light coming form sun. When approaching light beam is in angle lower than 50 degrees, majority of energy is than reflected away from window. But at the turn of June and July, sun is rising right above the park located ahead of testbed where no buildings shadowing direct morning beams. In this time of the year, it is vital fo close shading before presentation or to have HVAC running from early morning.

Insufficient HVAC in summer From simulation of temperature properties during presentations, 5.4. It is clear that during summer time, HVAC cannot compete with energy gains from sun and people. I have set HVAT simulation settings to minimal inlet air temperature is 19 ℃ because of comfort inside. Simulation shows that this is not sufficient and if we want to keep temperature at maximum of 26 ℃ during summer, HVAC has to be started about 2 hours before presentation to chill testbed down to 21 ℃.

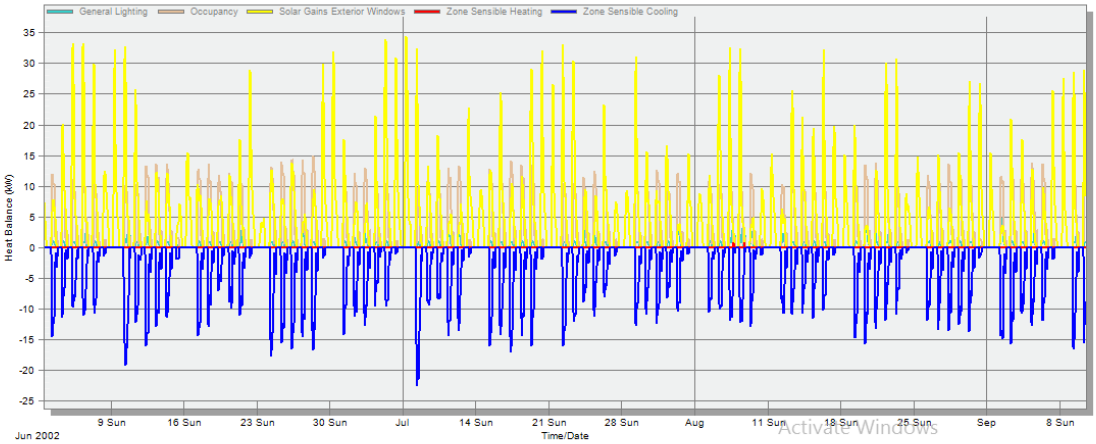

Figure 5.3: Graph of energy gains in testbed, we can see part from June to September. Quelle: Author

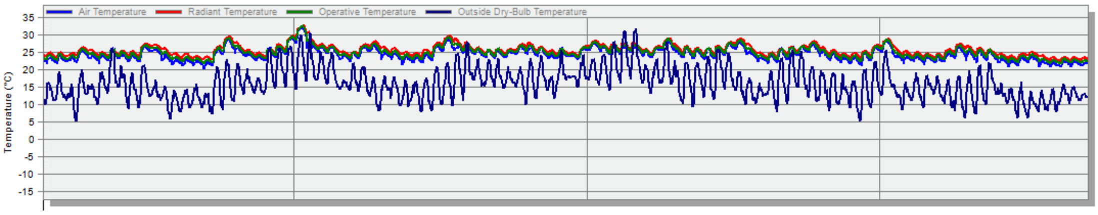

Figure 5.4: Graph of temperatures inside testbed from June to September. Quelle: Author

Low temperature gain from technology When I have preparing simulation data, I have collected energy sheets for all installed technology in testbed. It turns out, that energy contribution from installed industrial technology and presentation HW (television, projectors) is only about 9kW. When we relate it to area of testbed, it is less Wats per square meter than in standard office. Thanks to that, we don't have to use special HVAT regime or settings for Testbed.

5.2 Example: Energy efficiency of Testbed

I have described in 4.4 energy modelling in RAMI 4.0, in this section, I am describing tools used for energy efficiency in testbed. All systems that are implemented are in conformity with ISO 50001 and all measures that I have installed are following ISO 50001 methodology.

5.2.1 Profienergy savings

PROFIenergy described:[25] is profile based on PROFINET that allows to control energy profile of installed technology. It allows to switch off, standby or wake parts of manufacturing process without requirement for additional wiring. It handles typical plant states of its energy profile:

- Brief pauses - for maximal one hour, generally during workers breaks or when specific station is not in use.

- Longer pauses - hours/days long, to switch off during nights or during factory downtimes. In testbed, this is most interesting profile for implementation because of regime that is testbed operated under.

- Unscheduled pauses - mainly because of equipment failure, with this profile it is possible to take machines into energy safety state. Interesting in cooperation with BMS during building emergency situations.

- Load measurement - currently we are measuring only 4 different energy consumption profiles in testbed, with possible measurement thru PROFIenergy we can bring even better transparency into system.

Implementation of PROFIenergy profiles on testbed is done in main controller, CPU PLC S7-1518 where are as well located our energy consumption data. Thanks to integration into one system, we can implement data from PROFIenergy as next energy object and use analytics tools from Energy manager PRO and Energy suite to visualise them.

Energy switching concept

In testbed, I have implemented two states "Sleep" and "Ready", more energy states are not required because of special profile of testbed use, short time pause is no gain it this context. Most of the time, testbed is inactive and than, it has to be activated for only short amount of time.

- **Sleep** is longer pause of line production, it is implemented as switch off state for distributed system ET200SP inside control cabinet. The ET200SP unit is divided into two parts, cards for measuring energy and managing machine safety are powered on during sleep, this is required by safety norm 621061 and we want information about consumption during pause. Cards used as standard IO are powered off during sleep. Standard time for sleep is 8 hours. Base unit of ET200SP is keeping full Profinet capabilities during break.

- **Ready** is standard state of testbed, it is ready for production and all devices are powered up.

I have implemented PROFIenergy only for main control cabinet. I have prepared implementation for rest of control cabinets, PROFIenergy can be implemented during summer when there will be less traffic of people. During preparation of implementation PROFIenergy for robots, I have run into problem with robots safety. During discussion with KUKA engineers, I have found out, that to implement PROFIenergy for robots, there has to be some changes in their program in order to comply with machine safety.

Because of irregular use of testbed, switching states of testbed is implemented as button on main control panel in tab "Spotreba". Because of irregular use of testbed, it is to complex to automated it.

5.2.2 Light control from PLC

In [12] is description of fully automated factory, where no workers are on shop floor and machines are fully automated. There is no need for human presence. Investor can cut costs on light, air-conditioning and heating. We want prepare testbed for this type of production and first step is to learn how to control building lights from main control system of the line.

Lights and presence detector

All lights in testbed are connected via DALI bus and we can control them from 0% to 100%. We have divided testbed lights into 8 zoned that can be controlled separately, zones are visualise on 5.5 by red colour. We have as well take three light above line work stations and we cant control them separately, marked with yellow colour. From building system, we are getting data about people presence in production line area from PIR sensor in the cealing.

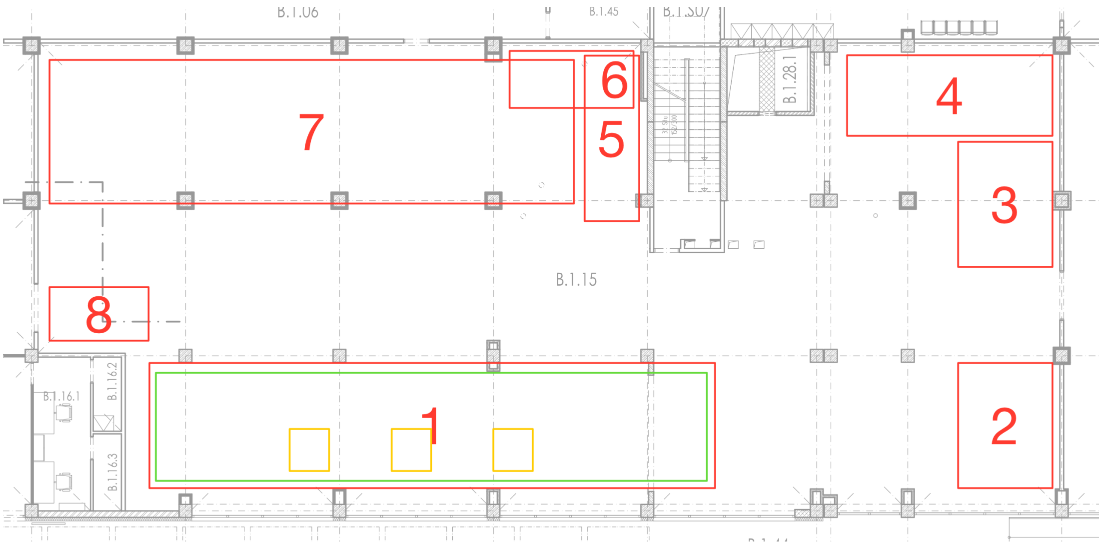

Figure 5.5: Light zones in Testbed. Reds are zones, green is zone with movement detection, yellows are single light for control. Quelle: Author

Connection from PROFINET to KNX

In order to get light control data from PLC that controlling line into BMS, it has to be converted between protocols several times. Graphical representation in RAMI 4.0 is on 5.6. When we go from HMI to Light:

- **HMI to PLC** (represented by orange) is connected via standard OPC connection and all connection is happening in TIA portal. From HMI control element, I am writing value into data block in PLC.
- **PLC to KNX** is connected via LOGO8 system, it offers native KNX gateway and connecting PLC to LOGO is not complicated. It is done via S7 connection (light blue colour), as server is implemented PLC and LOGO as client is reading values from data block writed by HMI. Data block has to be addressed directly. From LOGO to KNX gateway are data getting

via LOGO virtual memory(red colour). It is part of memory that can be read/write from network connection.

LOGO KNX gateway is implemented in ETS5 SW. We have set which part of V-memory in LOGO is responsible for which light zone. Only problem during this implementation was, that LOGO can propagate only Word data format (2 bytes) and lights are controlled via byte format. So addressing is quite tricky to achieve signing values into specific byte and not to use whole memory.

- **KNX to DALI** (green colour) is done by hardware located in building control cabinet out of our scope.

Similarly we are getting data from PIR presence sensor located above line. Presence is detected by standard array of 3 PIR sensors, detecting movement from 1m above floor. We are getting only aggregated information as bool value from all three sensors. They are detecting movement and set output to 1 for 20 seconds. Therefore we cannot use those sensors for machine safety or else. Only for setting lights above line. Sensor closes to main control cabinet is as well connecting point for KNX network from main control cabinet.

To control light from main HMI, go to energy page of HMI and there is settings for every zone. In order to control lights, you have to switch on light control. For presentation purposes, I have prepared light scene called ”presentation”, that pre set light zone in given order and percentage ideal for conferencing and presentation purposes.

5.2.3 Energy profile of testbed

Because testbed is not only production line, but mostly presentation space for industry 4.0 I have prepared two states for those premises:

- **Presentation** is state to be used for presentation purposes, lights are set it order to make space looks good and lights up important parts of line and testbed. PROFIenergy devices are awake and waiting for production.

- **Sleep** is used during rest of the time, light control from line is disabled. Lights can be control independently via standard wall switch. PROFIenergy devices are in sleep mode.

5.2.4 Energy interface description

In order to maintain open and standardised system, I have created description of testbed line in AutomationML. Because of AML is only descriptive format, We need protocol to transfer information. In this example is used OPC-UA, one of the biggest advantage of this protocol is, that it caries not only data but as well semantics of them. This is future proofing this protocol to be used as main communication protocol between production stations on testbed in near future.

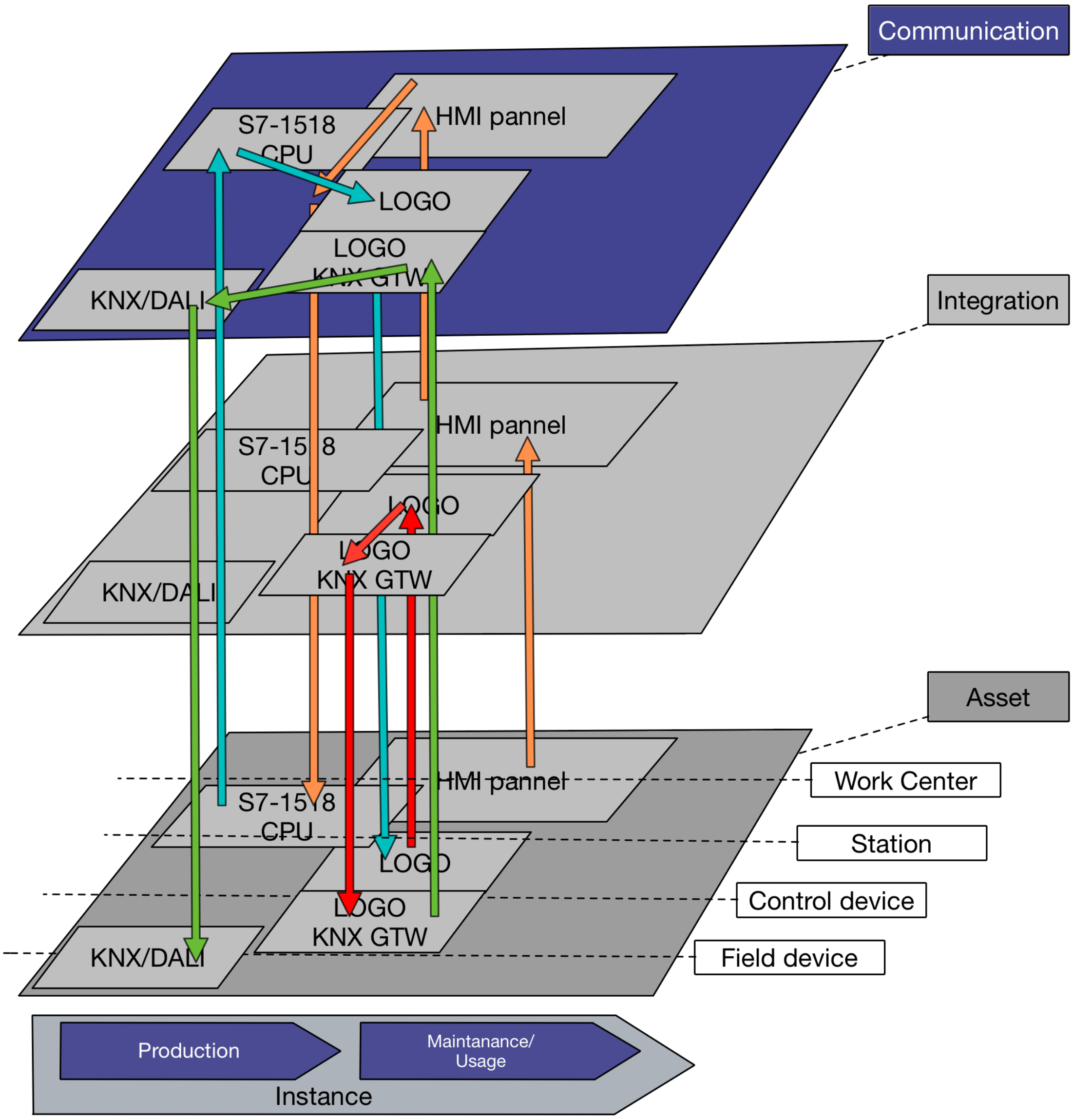

Figure 5.6: RAMI representation of light control described in 5.2.2. Quelle: Author

AutomationML description

Before creating information model for OPC-UA, I have created function oriented description of energy measurement on testbed. Because of high complexity of line, I have focused just on energy topic. Description in AML can be found in attachments. On 5.7 is screenshot from AutomationML editor, which I used for creating the model.

Base of the model, the HW configuration and communication structure, has been generated from TIA portal usinf TIA portal Openness function as CAx file and imported into AML editor. In editor I have imported standard libraries and connect required HW with standardised description.

In this step, I wanted to generate OPC-UA information model directly from AML editor, but in days of writing this thesis, there is no way of generating OPC-UA information model directly from AML. There are some tools how to do it, but i haven't been successful in reaching authors of those tools and getting

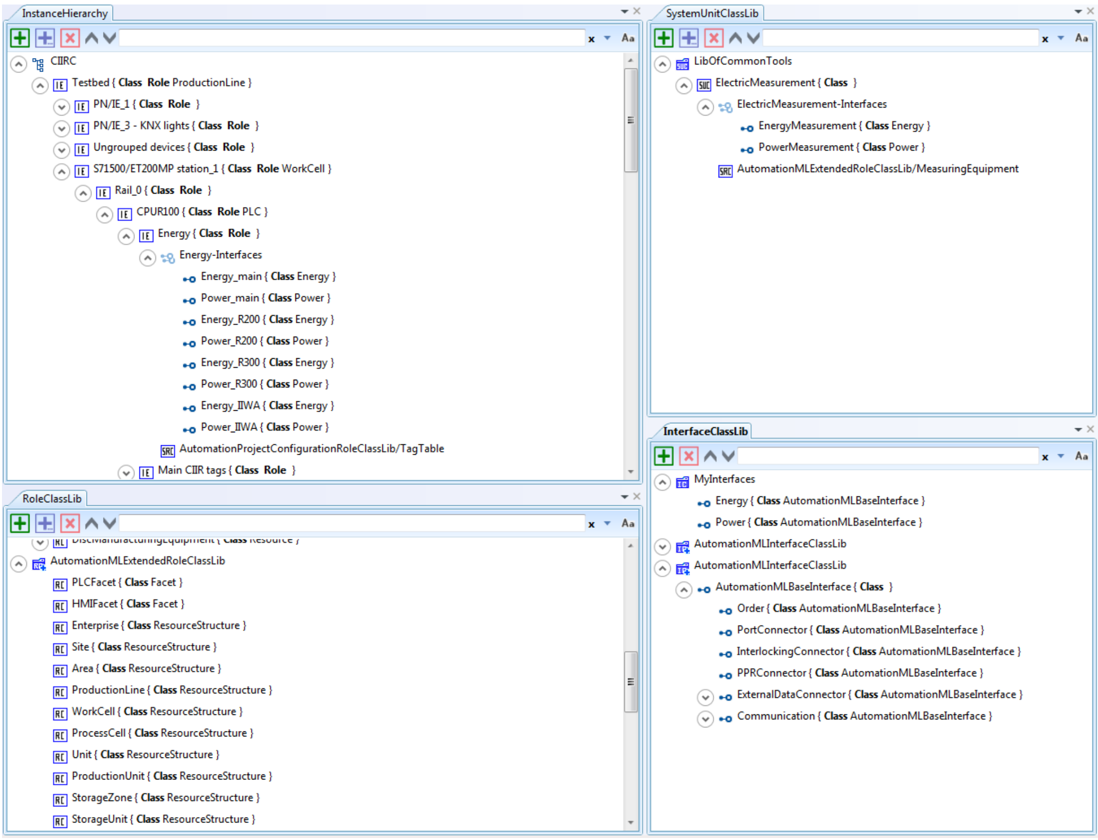

Figure 5.7: Screenshot from AML editor with visible structure of energy measurement. Quelle: Author

them.

OPC-UA information model

For creating information model I have used tool Siemens OPC-UA modelling editor. In our case, main advantage is integration of TIA portal project into editor, so I was able to map required variables directly into PLC data blocks. As starting point for my information model i have chosen EUROMAP 77 standard. I have chosen this standard, because it contains big library of standardised interfaces, lot of them are common with production on testbed.

In order to create information model, I have downloaded description of model from Euromap web pages and I have to create new TIA portal project. Modelling editor cannot work with locked project, so I have exported required PLCs out from project and create clean one without password. Mapping of variables into model is than shown on 5.8.

After export of information model with mapped variables, I can directly upload them into PLC and make them public on OPC-UA server of main PLC. In order to use this model, I had to upgrade PLC firmware to version 2.5.1.

5.2.5 Engineering standardisation

During programming of new features of line, I have also implemented two crucial parts of future testbed development.

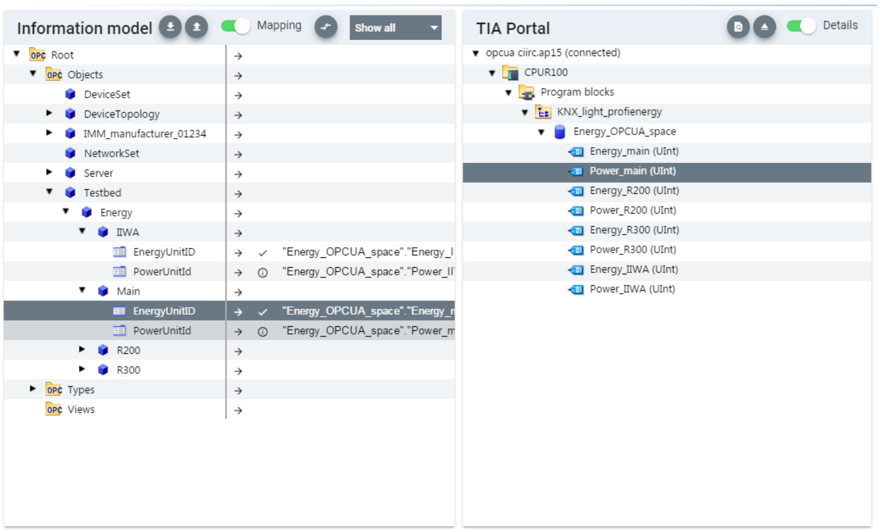

Figure 5.8: Mapping data block to semantics on information model. Quelle: Author

Testbed library of functions

As mentioned in [8] and [9], I have started library of functions for testbed. All function block created in this thesis are designed in comply with style and programming guide for Simatic controller. Library is part of automation project for TIA portal.

Multiuser engineering server

I have installed multiuser engineering server on IPC located in testbed. Main automation project is stored on this server with remote access. Multiuser server allows multiple people to work on one project or one PLC and managing changes and consequences of programmed code. It is tracking changes done by programmers, so we can always return to functioning version of project it error happens, see5.9.

This is as well solving problem with unauthorised changes of project, layer one is multiuser authentication, layer two is protection of project itself.

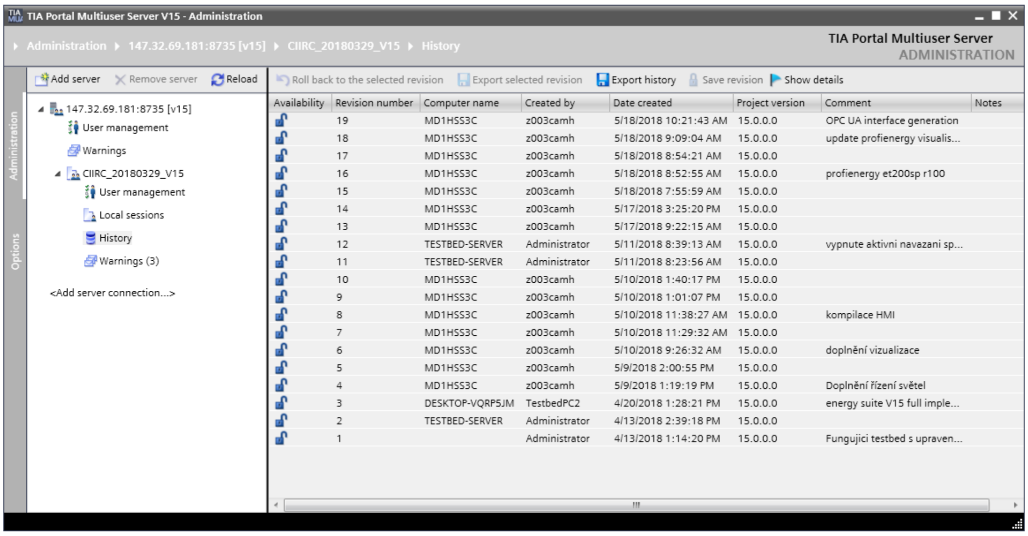

Figure 5.9: Project versions with changes commentary on multiuser server. Quelle: Author

Conclusion

In this thesis I have covered topic of energy efficient production with overlap into building information modelling. I have also covered new methods of holistic approach into design and service of production lines.

I have created model of testbed with simulation of thermal and energy flow. On this model I have discovered possible problems with solar radiation and designed and simulated possible solutions. Energy flow in production has been designed with automationML and propagated with dedicated OPC-UA information model. Unfortunately, due to lack of several information about production steps in PLC I have not been able to create full product energy dispatch note. I have created data connection between building system and production line. This connection is implemented onto same RAMI 4.0 model as production line. Line is now able to control light in testbed premises and collect information about people presence next to the line. I have implemented PROFIenergy protocol for devices in main control cabinet. Unfortunately, I haven't been able to implement them on robots located in heavy testbed.

One of the major ideas is, that interconnectivity of buildings and production lines on higher level of integration can help protect environment thank to lowering energy consumption. This interconnectivity has definitely positive economic impact during commissioning and operations of newly created production lines and factories. Also integration of these ideas onto brownfields can help reduce energy consumption and can increase quality of work conditions in older factories.

I believe, I have created good stepping stone for future development of testbed and opened cooperation between multiple sites involved in consultation and support in testbed.

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List of Figures

Attachments

In attachments, there is not provided TIA portal project due to security and intellectual property reasons. Following structure of attached folder:

```
dpTomasFronek.zip
├── building
│   ├── CIIRCtestbed.dsb
│   └── PUDORYS1.NP-B.dwg
├── automation
│   ├── testbedEnergy-OPCinterface.xml
│   └── CIIRCtestbedV15.aml
└── legacy
    ├── projekt1.pdf
    └── projekt2.pdf
```