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FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY
Institute of Nuclear and Physical Engineering

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Dissertation outline

Method for optimization of nuclear decommissioning using BIM-based holistic digital platform

Registration number: FEI-104394-18195

To obtain the academic title of philosophiae doctor, PhD.,
in the doctoral study field / programme
Electrical and Electronics Engineering / Nuclear Power Engineering

October 2023, Bratislava

Dissertation work has been prepared during the external doctoral study

at	**Institute of Nuclear and Physical Engineering** Faculty of Electrical Engineering and Information Technology Slovak University of Technology in Bratislava
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The defense of the dissertation is taking place on December 13, 2023 at 10:30 AM, at Faculty of Electrical Engineering and Information Technology STU, Ilkovičova 3, Bratislava, conference room A-616.

prof. Ing. Vladimír Kutiš, PhD.
Dean of the faculty

Table of Contents

Abbreviations

AI	Artificial Intelligence
AEC	Architecture, Engineering and Construction
ALARA	As Low As Reasonably Achievable
ANN	Artificial Neural Network
API	Advanced Programming Interface
AR	Augmented Reality
BIM	Building Information Model
CAD	Computer Aided Design
CDE	Common Data Environment
CERS	Comprehensive Engineering and Radiation Survey
DT	Digital Twin
GB	Gigabyte
HW	Hardware
IAEA	International Atomic Energy Agency
IFC	International Foundation Class
IFE	Institute for Energy, Norway
ISDC	International Structure for Decommissioning Costing of Nuclear Installations
IT	Information Technology
JSON	Javascript Object Notation
K-PIM	Knowledge-centric Plant Information Model
LC	Labor Costs
LCp	Labor Costs for the preliminary costing
LCd	Labor Costs for the detailed costing
LLM	Large Language Models
ML	Machine Learning
NPP	Nuclear Power Plant
OWL	Ontology Web Language
PIM	Plant Information Model
PLEIADES	PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES
PRIS	Power Reactor Information System
RAW	Radioactive Waste
REST	Representational State Transfer
SSC	Systems, Structures and Components
SW	Software
UAV	Unmanned Aerial Vehicle
UI	User Interface
VR	Virtual Reality
XR	Mixed Reality

1 Introduction

Digitalization in nuclear decommissioning projects is a long-term challenge due to the nature of the nuclear decommissioning projects itself. It covers several disciplines and areas of activities over a few decades. Digitalization of such a long-term process is a challenge due to a broad spectrum of required activities, including project planning, optimization, execution, and training.

Decommissioning of nuclear power plants requires large amounts of input data for the proper and effective planning or execution. On the other hand, it also generates large amounts of output data which may have an impact on real life decisions. An example of such a large data set is a 3D model file extended with information on radiological properties of particular objects in the model, which together represent an inventory database of the facility that is being decommissioned. Another typical data set is a point cloud file which can grow up to gigabytes in size.

One of the information necessary to plan the decommissioning process is also the operational documentation of the plant including the inventory database and characterization of the inventory. The digital twin or the Plant Information Model (PIM) can serve as a storage for such a database with an intuitive access to the data. The concept of knowledge management is very well described in [1]. The proper implementation and further utilization of such PIM increases the quality of knowledge, which, in turn, leads to the decrease of risks in decision making by making these decisions more informed, as illustrated in Figure 1-1 below. And, lower risks means higher safety.

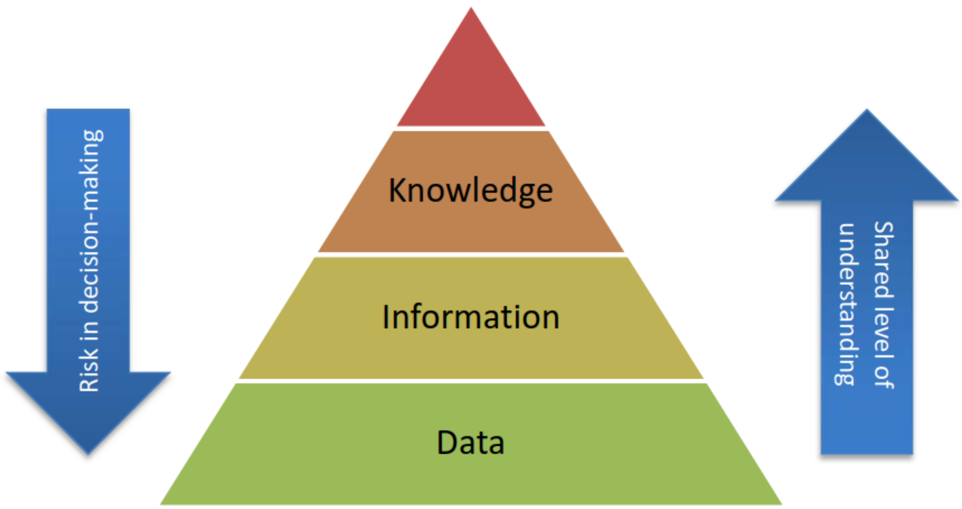

Figure 1-1 Knowledge hierarchy, level of understanding and related risk in making decisions

Very important role of the PIM is the effective exchange of the information between all parties involved in decommissioning. Common understanding among all involved teams increases the effectiveness of planning and decision-making as well as increases the security of staff performing specific activities. The PIM describes a common Nuclear Power Plant (NPP) language through which interactions and sharing of information can be managed. The PIM is not only an Information Technology (IT) data repository or a digital data hub, it is also the set of principles which help build a common language to support IT systems [1]. Moreover, in [1] following benefits and values of the PIM related to decommissioning phase of NPP are described:

1. To provide all decommissioning project stakeholders with the required design, engineering, production, operation and other relevant engineering and technical information through a single repository;
2. To facilitate development of integrated 5D or 6D simulation models based on PIM for disassembling high-level equipment and structures of NPP with concurrent calculation of radiation dose rates, generated radwaste amount, required activities, schedules, resources, and cost evaluation;
3. To calculate generated radwaste amount based on data about NPP radiation condition, contamination and geometry accumulated in PIM;
4. To ensure effective and safe decommissioning performance pursuant to a design with the aim to reach specified final state by means of developing and further using a PIM that consolidates all required engineering data, comprehensive engineering and radiation survey (CERS) data, as well as visual representing of decommissioning works in progress on simulating models.

All the previously mentioned concepts may and also should be adapted also for the decommissioning. In this work I first present the overview of the digitalization technologies and the current state of their utilization in the decommissioning. Afterwards, I describe the concept for the development of the holistic digital platform for the support of the decommissioning and demonstrate this concept on a selected use case.

2 Current state of the art in the digitalization technologies and decommissioning

From my own experience – participation of R&D projects focusing on digitalization of decommissioning; presence at various conferences, including providing presentations; participation at international workshops organized by the International Atomic Energy Agency (IAEA) – I can recognize that research efforts are focusing mostly on following digitalization technologies:

- Utilization of 3D models and BIM processes, e.g., to simulate decommissioning activities and identify risks, estimate costs or estimate dose uptakes;
- Utilization of Digital Twins (DT), e.g., for modelling the radioactivity characteristics of the most irradiated components;

- Utilization of AI and ML, e.g., for the mission planning and optimization of robot routes;
- Utilization of Large Language Models (LLM), e.g., for processing of electronic documents;
- Utilization of voice recognition technologies, e.g., for the digitalization of the inspections;
- Implementation of holistic digitalization platforms (common data environments, CDE) for centralized storage of the decommissioning data.

2.1 3D visualization and Building Information Model (BIM)

Utilization of 3D models to mimic the real world has already quite a long history. First pioneering technologies were rather simple, paradoxically, the history of 3D modeling began way before the first personal computers appeared. The first advancements in the history of 3D modeling came when the first commercially available CAD or Computer Aided Design systems started coming out in the 1960s. Further enhancements of 3D visualization techniques and rapid increase of the computational power of personal computers enabled the development of the Building Information Models (BIM). As per [2], there is no unique definition for the “BIM”. Simply said, BIM is a “smart” 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure. An example of real utilization of BIM models in work planning not only for decommissioning of nuclear facilities is a clash detection. This process helps avoid situations that would block performing planned work because of collisions e.g., when moving large objects. Figure 2-1 above shows an example of such clash detection using a BIM model [4].

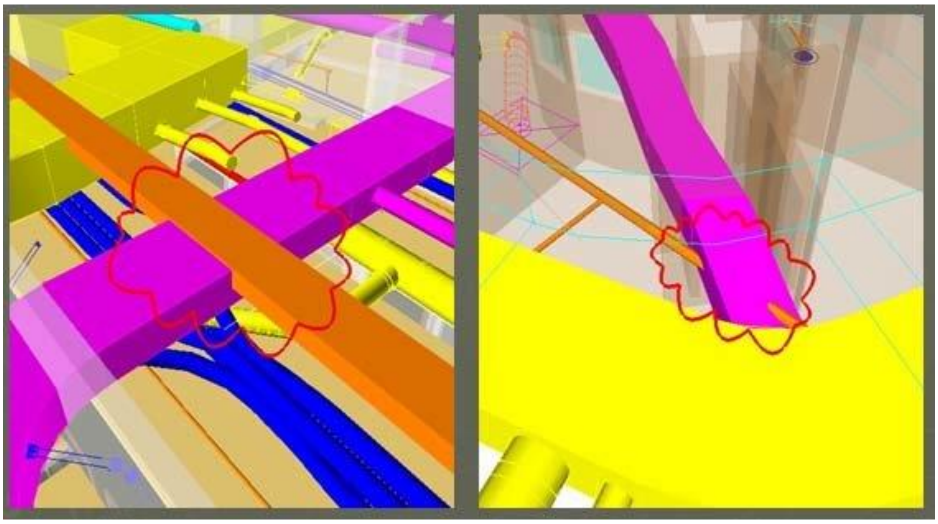

Figure 2-1 An Illustration of Clash Detections via Building Information Modeling (Courtesy of: PCL Construction Services, Orlando, Florida, USA)

2.2 Digital twin

Digital twin is a virtual clone of an object or an asset that holds not only visual information of that object (e.g., the 3D model) but also various data, models, processes or even algorithms assigned to it. It is the highest level of digital modeling of a particular building or plant. Using a digital twin a person can obtain a view on the object from various perspectives, can benefit from its mathematical modelling features, and take necessary decisions or actions to maintain or improve the object. In addition to static information stored in a digital twin, a digital twin can also hold information to processes performed over an object and it is often useful to store timestamps of the information so that a historical view of the object can be obtained. Digital twin technology can have the potential to change the working habits in many areas of the nuclear power industry. This potential of utilization of digital twins is illustrated in the Figure 2-2 below which illustrates the complexity of the topics and disciplines in the nuclear industry that can be covered by the digital twins [6]. The figure also illustrates that there is a working process behind, in order to achieve the most effectivity from implemented digital twin. The process includes data acquisition (orange part), analysis of this data in the virtual space / 3D models (cyan part), identification of necessary actions and recommendations (green part) and execution of these actions in the real world (blue part).

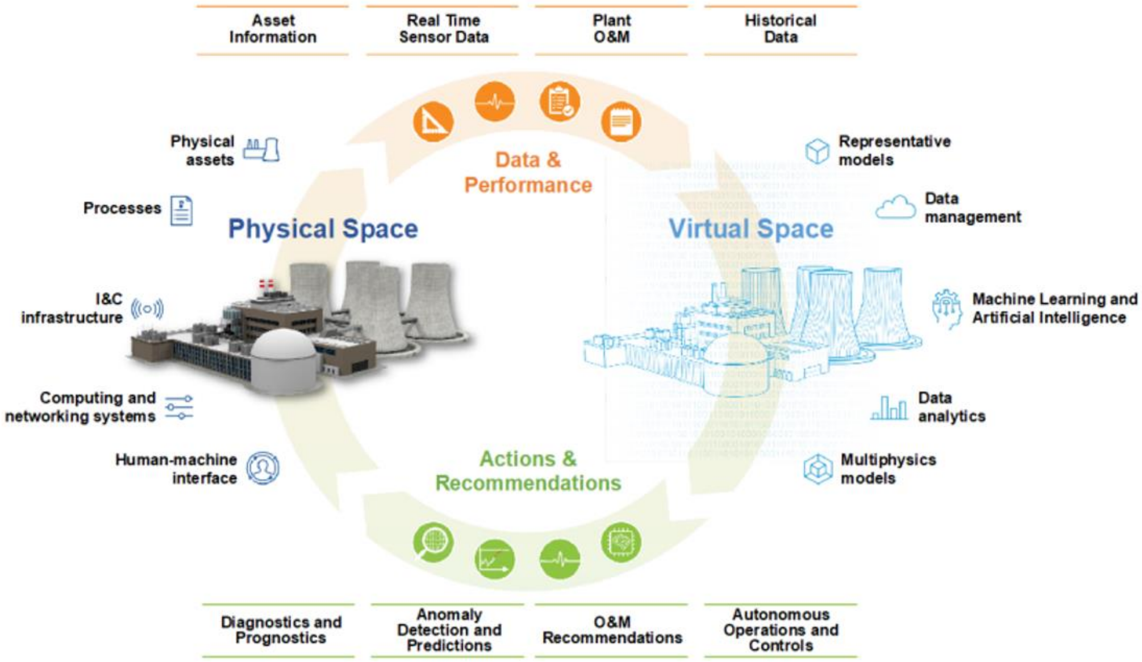

Figure 2-2 Illustration of potential for utilization of digital twins in the nuclear industry

2.3 Virtual, Augmented or Mixed reality

Computational power of modern computers or even mobile devices dramatically increased in a very short period. Now-a-days we can easily use handheld devices to display 3D models in real time and allow them to read the actual position of the user and to detect the rotation of the device using the integrated gyroscope. Additionally, new peripherals allowing for real-time monitoring of human's hand movement and head rotation are available on the market. As an example, interesting research focusing on a real-time human-robot interaction using static hand gestures and 3D skeleton extraction is presented in [9].

2.4 Wireless networks

Wireless technologies are for monitoring and safety reasons much wider used in other industries compared to nuclear. Adoption of such technologies in the nuclear world is significantly slower due to nuclear regulations, laws, public acceptance, safety concerns and some other technical barriers of those technologies. However, the trend is clear, wireless technologies are regularly evolving and economic advantages for deployment of such systems are becoming more and more visible. For decommissioning of NPPs and especially those in which any accident occurred during the operation the constant monitoring of radioactivity is also of concern. In [16], a study on application of wireless technologies in Nordic NPPs was carried out. Table 2-1 below summarizes proposals for these applications grouped by different stages of the NPP's lifecycle. It can be seen from this study, that wireless technologies can be most often applied in decommissioning than in normal operation.

Table 2-1 Proposals of application of wireless sensor networks in Nordic NPPs

Wireless application candidate	**Normal operation**	**Annual outage**	**Service operation before decommission**	**Decommission**	**Emergency**
Wireless infrastructure definition and setup	X	X	X	X	X
Radiation monitoring in the perimeter of the plant	X	X	X	X	X
Dosimeter monitoring inside the plant	X	X	X	X	X
Document and information retrieval	X	X	X	X	X
AR / VR applications for maintenance	X	X	X	X	X
Drone inspections with carry on sensors	O	O	X	X	X
Remotely operated robots with carry on sensors	O	O	O	X	X

Legend: X – applicable, O – optionally applicable

2.5 Laser scanning and point clouds

Point cloud is another way of representing the physical object in a virtual space. As the term suggests, the point cloud is a large set of points in a space captured by a 3D scanner. Point clouds, together with vector-based 3D models, are used to virtualize a physical object or an asset and to simulate various scenarios upon this object. In decommissioning it can be used to simulate and plan specific dismantling activities and to estimate dose uptakes of workers, durations and costs of these activities. In [22] the method for extraction of 3D objects in point clouds based on primitive detection is presented. The proposed method is fairly new to solving various problems related to extracting semantically rich information from a nontraditional type of digital data, especially hybrid point clouds created from laser scanning. As illustrated in Figure 2-3, the method is split into several steps (input points, edge detection, clustering and segmentation, candidate surfaces, results) and is capable of extraction quite complex structures [22].

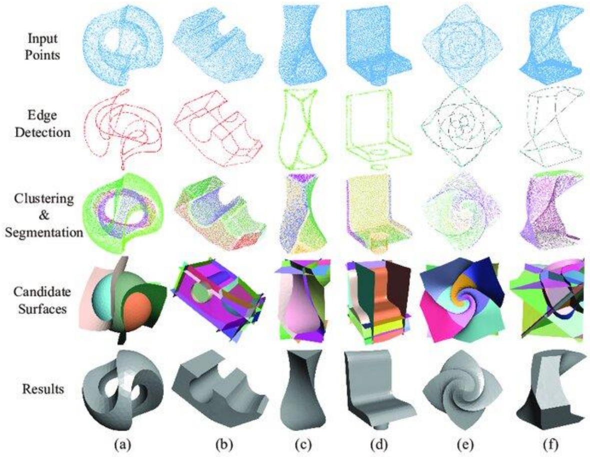

Figure 2-3 Demonstration of the method for extraction of 3D objects in point clouds

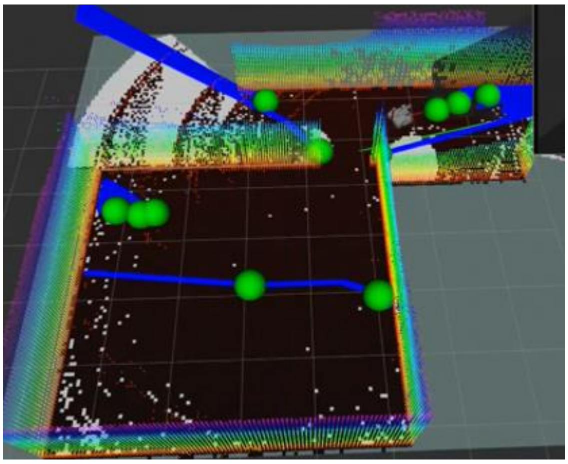

Figure 2-4 Image processing based on samples taken by robotic platform in combination with artificial intelligence

2.6 Robotics

Collecting the information about the actual status of the decommissioned facility can in certain situations and locations be a dangerous task or a very time-consuming task. On the other hand, the more relevant data we have, the better planning and optimization of the project we can do. Numerous research activities are currently focusing on development of fully or semi-autonomous robots able to reach areas which were not accessible by today or the measuring exercises would take too much time. An example of utilization of such robots is the robot for mapping and monitoring contamination in the area, as illustrated in Figure 2-4 [27].

2.7 Unmanned Aerial Vehicles (Drones)

Unmanned vehicles have numerous advantages for nuclear safeguards and security. A primary advantage is that radiological assessment tools no longer must be constrained by the physical limitations of a team of nuclear workers. Instruments can be attached to unmanned vehicles and be transported to areas a human would generally not be able to access. An example of utilization of drones and UAVs can be found in [31].

2.8 Big Data

If we want to utilize the real-time monitoring of a nuclear power plant during its whole life cycle (mainly the operational phase), we must be prepared for storing a very large amount of heterogeneous and loosely structured information. The pre-design, design, commissioning, and operation base of a BIM encompasses an extensive amount of information, which is needed during the decommissioning phase [1].

2.9 Artificial Intelligence and Machine Learning

The Artificial Intelligence (AI) and Machine Learning (ML) are currently probably one of the most often referenced term when discussing the new emerging digital technologies across all industries. This technology inarguably brings new paradigms in the digitalization era and has a potential to develop brand new processes in data management, automation, training, simulation, etc. However, as with any form of information processing, they are subject to the limitations of information linked to the way in which information evolves in information ecosystems [34]. These limitations, especially in the nuclear industry, are very closely related to the safety and reliability of the information provided by the AI technologies. The main driver for these limitations is the amount of reliable input data which can be used to train the AI algorithms to provide reliable outputs.

An example of such utilization of the AI is described in [35]. In this study, a feed-forward backpropagation artificial neural network (ANN) model was trained to simulate the interaction between the reactor core and the primary and secondary coolant systems in a pressurized water reactor. The transients used for model training included perturbations in reactivity, steam valve coefficient, reactor core inlet temperature, and steam generator inlet temperature. The principles of training the AI models (feed-forward and back propagation) are illustrated in the Figure 2-5.

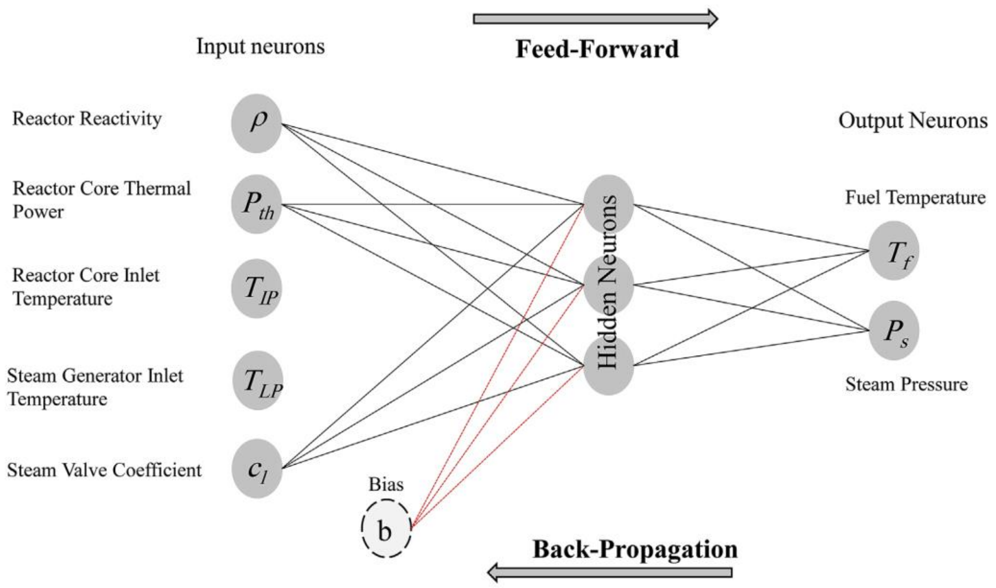

Figure 2-5 Schematic Diagram of ANN employed in the present study to simulate the dynamic behavior of a PWR

2.10 Plant Information Management

A Plant Information Model (PIM) is a specific implementation of the BIM matched to the business model of an NPP. The specifics of PIM are related to the NPP structures, systems, and components. Another definition in [1] says that PIM is a set of interlinked information about plant structures, systems, and components, incorporating plant data, relationships and rules used to integrate, represent, and describe nuclear facility processes and data for each phase of the facility life cycle. The most modern concept for implementing the PIM is the knowledge-centric concept. Compared to a traditional document-centric concept, the knowledge-centric concept does not only collect and store the information in a form of documents, but it also enables management of the knowledge generated from these documents or from processes in which the documents are used. As illustrated in the Figure 1-1, knowledge has a stronger ability to support decision making, than plain, simple data or information [1].

2.11 Common data environment

Digital platforms have notorious implications for the economy given their inherent separation between physical and virtual assets and the value created by them [36]. For this reason, holistic support systems that cover all aspects of a nuclear decommissioning are currently being researched. Holistic approach in digitalization has been adopted in many industries and areas of life like social care [37], construction [38], but also others.

Decommissioning planning has, in principle, 3 phases:

- Initial planning during the design, construction, and authorization;
- Preliminary planning during the operation;
- Detailed planning starting several years before the planned shutdown of the plant and lasting throughout the whole decommissioning project.

Each phase of planning requires slightly different set of data at a different level of accuracy. Using IT infrastructure based on the Common Data Environment (CDE) principle from the very beginning of the plant's lifecycle helps to collect and manage the data required for the decommissioning planning. There is one, very typical, set of information that can be considered as important for all phases – the inventory database with the radiological characterization of the facility. Sometimes this–is referred to as a list of equipment or a systems-structures-components (SSC) database. As per [43] and [44], the inventory database has three main components: Inventory of systems, inventory of structures and radiological parameters.

My personal experience also shows that development of the inventory database is a complicated process which even the employees of the operator do not understand clearly. This is additional signalization, that the standardization of this process can make the decommissioning planning more effective.

3 Objectives of the dissertation

Main goal of this work was to **propose and demonstrate new methodology for optimization of decommissioning planning for the digital era**. This methodology is based on using the holistic digital support platform based on the 3D/BIM modelling principles. Key challenge to solve was the integration of various specialized software tools used in the decommissioning planning, which are very often built on different technologies, running on incompatible operating systems and using incompatible data structures.

These software tools are often very valuable for the decommissioning planning itself, but the transfer of the data they require (the inputs used to work with the software) is done manually, without any automation. **The automated transfer of the data between these software tools is the main observable result of this work.**

To achieve this results, first **the common language** among all involved work teams and software tools used must be developed and this, in turn, leads to the definition of **the standardized protocols to transfer the data**.

Having the standardized protocol defined, the last step is to develop the platform using this protocol and to customize the software tools to use this platform. T**he results have demonstrated using two software tools** – AquilaCosting (developed in Slovakia) and VRdose (developed in Norway) and on a selected real-world use case – estimation of costs for the selected component of the 3D model.

The official goals of this work are as follows:

1. Scientific research in the field of digitization of nuclear power plant decommissioning planning, analysis of currently used technologies
2. Design of a method for optimization of nuclear decommissioning planning by using of holistic digital platform
3. Modeling and simulation of selected decommissioning work using a selected 3D model and near-real-world input data
4. Demonstration of integration of specific software tools using a common API interface
5. Evaluation of the improvement of work efficiency in planning of the decommissioning of nuclear power plants using the researched method
6. Recommendations for the further research and utilization of the investigated method in practice

4 Proposed implementation methodology

In this practical implementation I am demonstrating the integration of two different software tools dedicated for specific tasks in nuclear decommissioning planning, into a single ecosystem using a common ontology for decommissioning planning and an API developed in the PLEIADES project ([47], [48], [49], [50] and [51]).

4.1 The PLEIADES project

Recent research activities in the digitalization of decommissioning planning were focused on the development of a prototype of a holistic digital support system with the use of BIM modelling principles. This research was performed under the EU co-funded international project "PLEIADES" (PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning ProcessES) funded by EURATOM Research and Training Programme 2014-2018 under the Grant Agreement n°899990 which started in October 2020 finished November 2023. Fourteen international partners were involved in the project from seven countries; project duration was set to three years. Figure 4-1 illustrates the basic concept of the project [47]. The results of the PLEIADES project were demonstrated on three use cases - facilities from Norway, France and Spain.

Idea of the project was to develop an interconnected ecosystem of various different specific software tools; all connected to the system by using the same "communication language" based on the common ontology and the central server with the API.

Research activities in this project were split into following areas:

- development of standardized ontology structure for decommissioning;
- development of functional requirements for a holistic digital support system;
- development of technical aspects like communication protocol, overall IT architecture and required hardware resources to deploy, operate and maintain such system;
- development of validation tests and test environments for validating the overall concept and architecture.

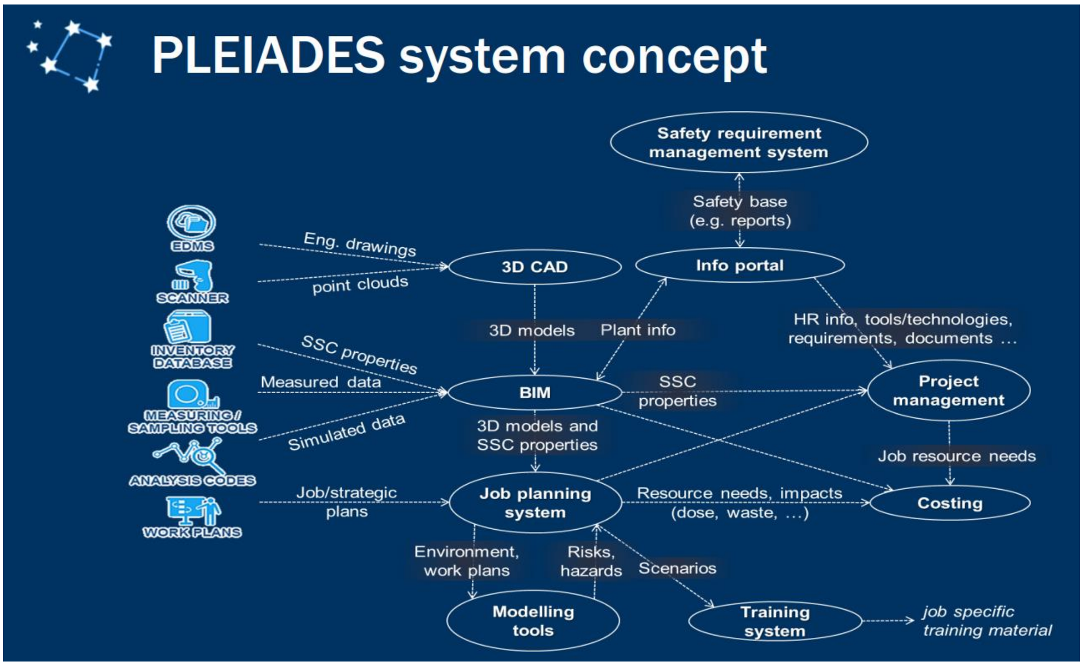

Figure 4-1 Overview of PLEIADES system concept

The concept of the platform and its basic architecture was also described in paper [46].

Results of PLEIADES project research identified following topics which should be addressed to successfully develop holistic digital decommissioning support:

- functional requirements, needs and expectations ([47], [48]);
- ontology structure for nuclear decommissioning [49];
- technical aspects of common communication protocol and common data storage ([50] and [51]);
- relevant validation tests and test procedures and Key Performance Indicators (KPIs) [52].

Functional requirements for the PLEIADES system prototype have been collected using online surveys, at conference workshops and in internal meetings and discussions of the research group. Extract of most interesting functional requirements is shown in the Table 4-1 below [47].

Table 4-1 Functional requirements for holistic digital decommissioning support system identified in PLEIADES project

Functional requirement
3D/BIM based inventory management with focus on risks (e.g., radiological)
Aggregate all radiological data in a 3D model-based interface incl. historical
Filter radiological data (for SSCs, time, status, DQOs)
Improved control over data management
Mapping completeness of inventory (filter: missing / estimated / validated)
Scenario simulation for analysis / optimization of plans
Compare alternative detailed plans in terms of dose
Better understand work plans
Detect physical clashes
Estimate radiological exposure to workers
Improved training by use of 3D visualization
Safety and risk management
Improve current safety demonstration practice
3D model-based facility/site overview of risks (risk register) – identify critical risks, filter risk info
Improved uncertainty estimations
Better anticipation of unforeseen
Identify parameters with highest impact onto project performance
Trace back decisions (who, why …)
Monitoring
Compare ‘as planned’ with ‘as performed’ data
Detect discrepancy between predicted ALARA estimates and data from monitoring during implementation
Benchmark cost estimates using data from completed tasks
Improve updating of cost estimates in case of deviation from assumed inventory
Regularly updated info on location of items – traceability from initial to final location
Waste route planning
Optimize waste streams
Compare alternative waste routes (costs, time, …)

My main personal commitment in this project was the design of the technical architecture of the platform and leading of the software development activities resulting in the functional server-based database capable of connecting various nuclear decommissioning planning software tools using a common API and common database for storing the data.

In this dissertation, I am using the platform developed in the PLEIADES project to demonstrate the interoperability of various software tools used in detailed decommissioning planning and to describe a proposal for the methodology of increasing the effectiveness of the decommissioning planning.

4.2 Goals and expectations

Main goal of this work was to conduct a feasibility study for utilization of BIM-based digital technologies to optimize the decommissioning projects, in particular dismantling activities with a risk of high dose uptake by the workers. Second side-effect was to demonstrate the capabilities of modern technologies to create a holistic digital nuclear decommissioning support system with a focus to improve the planning and management processes of nuclear decommissioning.

Goal #1: Design of a method for optimization of nuclear decommissioning planning by using of holistic digital platform

Results of the first two work packages of the PLEIADES project (WP1 and WP2) are in alignment with this goal. The results are described in relevant deliverable documents of the project, namely, [48], [49], [50], [51] and [52].

Goal #2: Modeling and simulation of selected decommissioning work using a selected 3D model and near-real-world input data

To achieve this goal, two software tools were used (see chapter 3.4.1) - VRdose and AquilaCosting. These tools are using the data transfer concepts developed in the PLEIADES project to exchange required data between each other. I am using these tools to demonstrate a selected decommissioning work using a 3D model of the Halden research reactor. Details of the work are also described in [51].

Goal #3: Demonstration of integration of specific software tools using a common API interface

The integration of the software tools is a requirement in the previous goal. Therefore, this goal is achieved simultaneously with the modeling and simulation activities.

Goal #4: Evaluation of the improvement of work efficiency in planning of the decommissioning of nuclear power plants using the researched method

The evaluation is performed after all modeling and simulation activities were performed and is discussed in the chapter 4 Results.

Goal #5: Recommendations for the further research and utilization of the investigated method in practice

Similarly to the evaluation, the recommendations raised from the work were described in chapter 6 Recommendations.

4.3 The demonstration

4.3.1 Identification of work steps

The work is focusing on demonstration of utilization of the central database (a “single source of truth”) for the decommissioning planning projects to extend the effectiveness of collaboration between different teams and disciplines involved in the decommissioning planning.

To successfully demonstrate the benefits of such approach, I had to:

- Identify the decommissioning planning tasks which I will perform;
- Select the software tools with which I will perform the tasks;
- Prepare the working environment;
- Prepare the input data.

4.3.2 Preparation of the environment

The environment for this work consists of following main components:

- The PLEIADES compatible central server with the database;
- The AquilaCosting software tool and VRdose software tool.

To prepare the environment, I needed to perform following activities: Install and configure the required software; Create the common database; and Connect the software tools to this database. The Figure 4-2 below illustrates the connection diagram between all components.

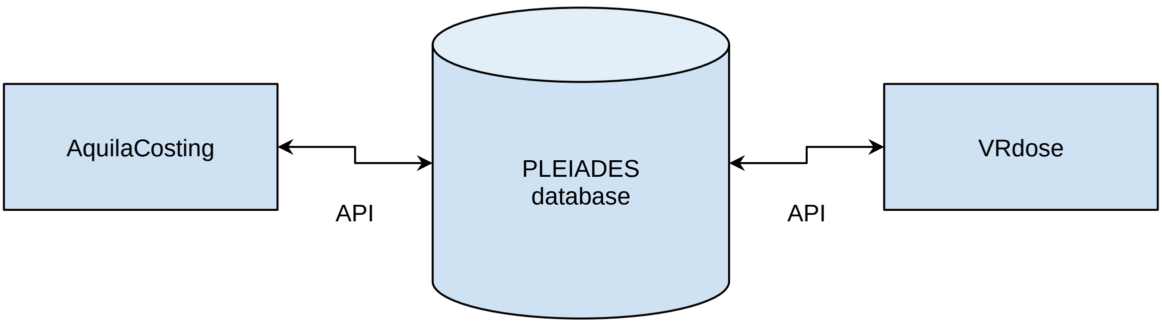

Figure 4-2 Connection diagram between the AquilaCosting, VRdose and PLEIADES database

4.3.3 3D model - Halden Research Reactor

I have used the simplified 3D model of the Halden Research Reactor. The rationale behind this choice was the model's manageable size and its suitability for use with the VRdose software.

In the Figure 4-3 below, the sample screenshot of a part of this model is shown. Format of the file containing the 3D model was ".ifc".

4.3.4 Component used for the demonstration

I have chosen a section of the piping as the component for which I conducted the cost estimations. Figure 4-3 also shows this component in a better detail. The reason why I have chosen this component for the demonstration, was the simplicity of the dismantling procedure and estimation of both detailed and preliminary costs for dismantling. Although the dismantling procedure is simple, it is sufficient for achieving goals of this work - to demonstrate the functionality and benefits of the common data environment. More details about the selection of the component can be found in papers [60] and [61].

4.3.5 Inventory database

Inventory database is a key source of information for both detailed and preliminary costing. In the detailed costing, it can have the form of a 3D model and in the preliminary costing, it is often a structured table containing the list of components to be dismantled or demolished and the physical or radiological information about each component.

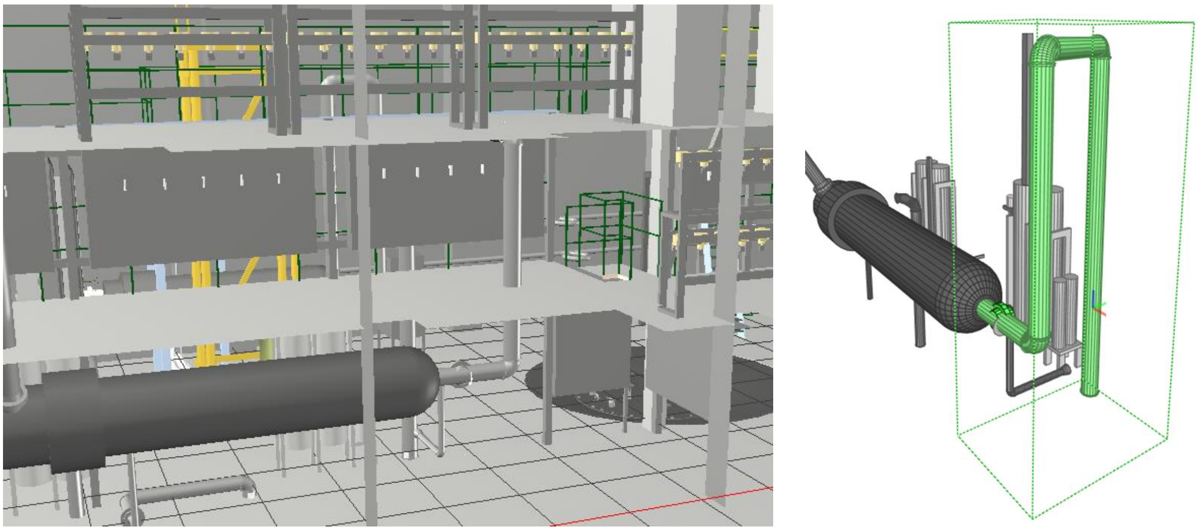

Figure 4-3 Sample screenshot from the 3D model of the Halden Research Reactor and piping selected for the demonstration of this work (courtesy of IFE, Halden)

4.3.6 Work orders and simulation of the dismantling activity

After the selection of the component, the appropriate dismantling strategy had to be selected. For the demonstration, I was assuming standard cutting of the piping using the grinder tool. This selection determined the working group and work orders necessary to perform the dismantling activities.

The Table 4-2 below summarizes the dismantling activities which I have simulated in the VRdose software. Further reading is available in [60] and [61].

Table 4-2 List of simulated work orders

Microtask
Initial position
Put on protection suites
Gather dismantling equipment
Move to the workplace
Perform cutting
Place fragments to the waste package
Perform final radiological survey
Move to the exit
Check for contamination
Change cloth

4.3.7 Cost factors and general input data

Following cost factors and other general input data had to be collected:

- Salaries of the workers;
- Physical characterization of the selected component (material, masses);
- Definition of the working groups

Additionally, duration of each work order is also a very important input - this has been obtained from the simulation in the VRdose software.

4.3.8 Simulation of the dismantling activities

For estimating the costs during the detailed planning phase, the 3D-modelling techniques can be used. In this work, I have used the VRdose software. Following activities were performed:

1. Load the 3D model of the room into the VRdose software;
2. Define the working team and store its definition in the PLEIADES database;
3. Simulate the dismantling task in the VRdose software and export the results into the PLEIADES database;
4. Import the simulation results and other relevant input data (e.g. hourly salaries) into the AquilaCosting software;
5. Estimate the costs of the AquilaCosting software;
6. Upload the results back into the PLEIADES database.

The dismantling task simulated in the activity #3 was split into several sub-tasks. These sub-tasks are summarized in a Table 4-2.

4.3.9 Transfer of data from VRdose to AquilaCosting software

The key point of this demonstration is to showcase that the transfer of the data between the two used software tools can be done semi-automatically or even fully automatically. For this purpose, the central database (a.k.a. single source of truth) with a well-defined API was developed within the PLEIADES project.

By having the API, which is well described, understandable and easy to implement, the particular software tools can implement their “connectors” - modules which are capable of communicating with the central database using the API. These connectors were implemented both in AquilaCosting software and VRdose software.

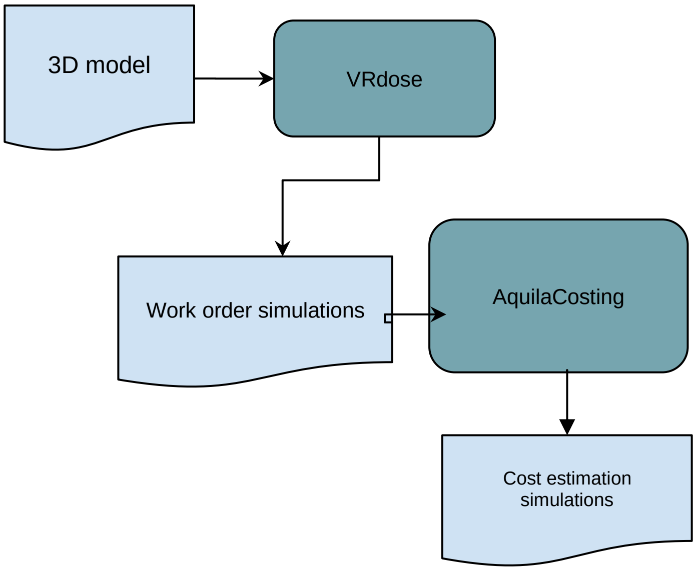

Figure 4-4 Illustration of data transfer flow from the AquilaCosting to the Vrdose

For this work, following information were transferred from the VRdose to the AquilaCosting: List of work orders; Durations of simulated tasks; and Composition of the teams working on the tasks.

These data were imported to the AquilaCosting software and used to estimate the costs using the methodology for the estimation of costs in the detailed decommissioning planning [60]. The whole data transfer flow is illustrated in the Figure 4-4 above.

5 Summary of results and new experience, discussion and recommendations

There are two types of results in this work. First and the main result is the successful demonstration of the integration of different software tools via a common data environment platform, using the common ontology and the API with the data transfer protocol. This result cannot be quantified and only can be evaluated qualitatively. Thus, by presenting the second types of the results - the two cost estimations performed using the developed platform, is a proof of the feasibility of the proposed method. These cost estimations are presented in following chapters and also have been presented in papers [60] and [61].

5.1 Detailed cost estimations

The Table 5-1 below lists the estimated durations of microtasks as a result of the simulation in the VRdose software. The duration of cutting was estimated by applying the estimated cutting speed, pipe diameter, and the number of cuts. The Table 5-2 summarizes the hourly salaries for each member of the team used in the detailed cost estimation and Table 5-3 summarizes the final estimated costs. Total estimated costs (without contingency) are 584.74 EUR. Investments and expenses were not estimated. The contingency for the detailed estimation was taken from the recommended range for the ISDC 04 activity from the DACCRORD 2 report [44]. Considering the fact, that the detailed planning provides more accurate inputs to the cost estimation, the middle value of the recommended range was considered. Final value for the contingency in the detailed planning is 10%.

Table 5-1 Simulated durations of the microtasks

Microtask	Estimated duration [minutes]
Initial position	0
Put on protection suites	15
Gather dismantling equipment	3
Move to the workplace	4
Perform cutting	216
Place fragments into the waste package	34
Perform final radiological survey	15
Move to the exit	4
Check for contamination	6
Change cloth	18

Table 5-2 Hourly salaries used in the detailed cost estimations

Profession	Hourly salary
Technician	29.46 EUR / hour
Engineer	36.71 EUR / hour
Manager	49.24 EUR / hour

Table 5-3 Costs estimated for each micro-task

Microtask	Estimated costs [EUR]
Initial position	0.00
Put on protection suites	28.85
Gather dismantling equipment	5.77
Move to the workplace	7.69
Perform cutting	415.48
Place fragments into the waste package	65.40
Perform final radiological survey	28.85
Move to the exit	7.69
Check for contamination	11.54
Change cloth	34.62

5.2 Preliminary cost estimations

The Table 5-4 summarizes the hourly salaries for professionals considered in the preliminary cost estimation.

Investments and expenses for the preliminary costs have been calculated using the cost factors for the decommissioning category INV21 Piping, valves, and pumps as described in the DACCORD 2 report [44]. Additionally, the unit factor for the labor content (number of manhours necessary to perform the activity) was taken from the DACCORD 2 report, as well [60]. The Table 5-5 summarizes all these cost factors.

Table 5-4 Hourly salaries used in the preliminary cost estimations

Profession	Hourly salary
Technician	29.46 EUR / hour
Engineer	36.71 EUR / hour
Manager	49.24 EUR / hour

Table 5-5 Cost factors for the preliminary estimations of labor costs

Cost factor	Value
Workforce	27.4 manhour/tonne
Average labor rate	32.58 EUR / hour
Investments	12.1 EUR / tonne
Expenses	117.9 EUR / tonne
Work difficulty factor	5%

The mass of the piping was extracted from the 3D model, resulting in 470 kg. The contingency for the preliminary estimation was taken from the recommended range for the ISDC 04 activity from the DACCRORD 2 report [44]. The maximum, conservative value of 20% has been selected. A work difficulty factor of 5% has been included in the preliminary cost estimation as it is assumed that before the start of cutting the selected pipe, any other surrounding components will already be dismantled, and the area will be easily accessible for cutting the pipe. The reason for non-zero work difficulty factor is the elevation from the ground of the highest point of the dismantled piping.

5.3 Comparison of estimated costs

The comparison of costs can be performed thanks to the standardized presentation of these estimations. The ISDC structure, which is already widely adopted by cost estimation engineers in the world and is a standard for the presentation of decommissioning costs, was used to present the costs here, as well. Then, we decided to estimate costs for the dismantling of the same inventory item (component). This allows us to use the same ISDC activity at the very bottom level of the ISDC structure. As we are estimating the dismantling of the piping in the controlled area, the 04.0503 Dismantling of other primary loop components ISDC activity was selected to present the results.

Table 5-6 compares the costs estimated using the preliminary and detailed estimation methodologies. However, it is important to note here, that this comparison is not the main goal of this paper. This article presents two different estimation methodologies from the perspective of the structured database linked with a 3D/BIM model.

Table 5-6 Comparison of preliminary and detailed cost estimations

ISDC activity	**04.0503 Dismantling of other primary loop components**	
Cost category	**Preliminary**	**Detailed**
Labor	440,54	605,90
Investments	5,69	0
Expenses	55,41	0
Contingency (%)	20%	10%
Contingency (EUR)	100,33	60,59
Total costs (EUR)	601,97	666,49

5.4 Discussion

Based on the nature of the method which has been demonstrated, the evaluation of the increased efficiency cannot be calculated quantitatively, but only qualitatively. To evaluate the improvement of the work efficiency in decommissioning planning using the demonstrated methodology and the platform described in this work, the set of evaluation parameters have to be selected first. These parameters are:

1. Improvement of the work safety by reducing the risks and the dose uptakes;
2. Improvement of the decision-making by providing precise simulations and well-structured planning documentation;
3. Reducing the project costs by evaluating more than one scenario and comparing their costs.

By having the platform capable of connecting any software tool used during all above-mentioned decommissioning phases together (the planning, the dismantling/demolition/decontamination, and the waste management) and providing the data exchange standards, the effectivity of collaboration of all involved teams can be even more improved. Furthermore, in [60], some other topics, more closely related to the estimation of costs, have been discussed with relevant conclusions.

5.5 Further recommended activities in the context of Slovak nuclear power industry

The implementation and further development of a 3D-model based “knowledge-centric” PIM [1] gathering the knowledge for all planned, constructed, operated and decommissioned units together, and across all involved stakeholders (owner, operator, EPC contractors, regulatory bodies, government ministries, local public, etc.) - either at the national level or at the level of the owner/operator - should be considered as an important step towards making the nuclear power more safe, reliable and economically feasible. Since in Slovakia, the complete spectrum of knowledge, starting from the pre-design and ending with the final release of the site after the decommissioning, is vital and existing, the implementation of such a system is a real opportunity to move the digitalization of nuclear power forward.

As an example of a successful implementation of a similar project abroad, the plant information management system, acquiring data from all national nuclear power plants and utilizing modern digital technologies to achieve data security and integrity, such as blockchain, has been developed and implemented by the South Korean operation KHNP – the system is called DREAMS (Digital Real-time Enterprise Asset Management System) [62].

6 Conclusions

Digitalization of nuclear decommissioning using modern digitalization technologies is the next step in enhancing the overall effectiveness of nuclear decommissioning planning and execution, mostly regarding the safety and economics aspects of the decommissioning. However, because of a large variety of these technologies, the data that these technologies require and processes that are performed with these technologies, a common language and effective data transfer should be developed. This also means that enhancing the efficiency of the existing nuclear decommissioning planning strategies is significantly underscored by the necessity of a "knowledge-centric plant information system" PIM (K-PIM) [1]. As per [1], other lifecycle phases of the nuclear power plant can benefit from having the 3D/BIM support and K-PIM. Examples of these benefits and a quantification of improvements are provided, as well, in [1].

Unfortunately, the software tools focusing on a specific area of decommissioning planning or management are being used in an isolated way. These software tools are integrated at a very low level or not integrated at all, mostly because they use different technologies and work internally with different database structures. This isolation and low level of integration causes ineffective data transfer from one software tool to the another or even from one specialized team to the another.

This work demonstrates the results of such research activities and describes the methodology of an integration of the isolated software tools, namely AquilaCosting and VRdose, as illustrated in Figure 4-2. The demonstration is based on the comparison of the cost estimation activities of dismantling of a selected component, namely the preliminary and the detailed cost estimation.

It has been demonstrated that by using the common data environment with an API based on the common ontology is a feasible way of increasing the efficiency of decommissioning planning.

References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY. Application of Plant Information Models to Manage Design Knowledge through the Nuclear Power Plant Life Cycle. Vienna, 2020. IAEA TECDOC Series, TE-1919, ISBN 978–92–0–111120–3

[2] DOAN, D., GHAFFARIANHOSEINI, A., NAISMITH, N., ZHANG, T., REHMAN, A., TOOKEY, J., GHAFFARIANHOSEINI, A. What is BIM? A Need for A Unique BIM Definition. 2019. MATEC Web of Conferences. 266. 05005. 10.1051/matecconf/201926605005.

[3] CHEUTET, V., SEKHARI, A., CORBEAUX, N. PLM and BIM approach to support information management in nuclear decommissioning: a synthesis. Italy, 2018. 15th IFIP International Conference on Product Lifecycle Management (PLM 2018), Jul 2018, Turin, Italy. pp.104-114. ffhal-01847842f

[4] AZHAR, S., NADEM, A., MOK, J., LEUNG, B. Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects. Karachi, 2008. First International Conference on Construction in Developing Countries.

[5] GALIC, M. et al., BIM in planning deconstruction projects. Vienna, 2014; ECPPM 2014 conference

[6] VAIBHAV Y., HONGBIN, Z., et al., The State of Technology of Application of Digital Twins, 2021, Idaho National Laboratory, Oak Ridge National Laboratory, U.S. Nuclear Regulatory Commission, Letter Report TLR/RES-DE-REB-2021-01

[7] IBRION, B., PALTRINIERI, N., R. NEJAD, A. On Risk of Digital Twin Implementation in Marine Industry: Learning from Aviation Industry. 2019. Journal of Physics: Conference Series. 1357. 012009. 10.1088/1742-6596/1357/1/012009.

[8] ZEXUAN, Z., CHAO, L., XUN, X. Visualisation of the Digital Twin data in manufacturing by using Augmented Reality. 2019. Procedia CIRP, Volume 81, Pages 898-903, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2019.03.223.

[9] MAZHAR, O. et al. A real-time human-robot interaction framework with robust background invariant hand gesture detection. 2019. Robotics and Computer-Integrated Manufacturing, Volume 60, 2019, Pages 34-48, ISSN 0736-5845, https://doi.org/10.1016/j.rcim.2019.05.008.

[10] SZOKE, I., Institute for Energy, Norway, Halden. April 8, 2021. Personal communication.

[11] POPOV, O., IATSYSHYN, A., SOKOLOV, D., DEMENT, M., NEKLONSKYI, I., YELIZAROV, A. Application of Virtual and Augmented Reality at Nuclear Power Plants. 2021. In: Zaporozhets A., Artemchuk V. (eds) Systems, Decision and Control in Energy II. Studies in Systems, Decision and Control, vol 346. Springer, Cham. https://doi.org/10.1007/978-3-030-69189-9_14.

[12] TERJE, J., NIELS-KRISTIAN, M. Virtual and augmented reality in the nuclear plant lifecycle perspective. 2010. International Electronic Journal of Nuclear Safety and Simulation, 1(2), 94-103.

[13] GASTELUM, Z. N., et al. Proposed use cases for augmented reality for nuclear nonproliferation verification and training. 2016. Sandia National Laboratories, United States. https://www.osti.gov/servlets/purl/1530055

[14] SANDEEP, V. DIVYA, S., KANIKA, S. Network Topologies in wireless sensor networks: A review. 2013. IJECT Vol. 4, Issue SPL - 3, April - June 2013, ISSN: 2230-7109 (Online), ISSN: 2230-9543 (Print)

[15] CARLOS-MANCILLA, M., LOPEZ-MELLADO, E., SILLER, M. Wireless Sensor Networks Formation: Approaches and Techniques. 2016. Hindawi Publishing Corporation, Journal of Sensors, Volume 2016, Article ID 2081902

[16] ARTO, L., Wireless in nuclear feasibility study. 2018. VTT Technical Research Centre of Finland, Ltd., presentation

[17] GOMAA, R. et al. ZigBee wireless sensor network for radiation monitoring at nuclear facilities. 2013. 1-4. 10.1109/WMNC.2013.6548954.

[18] SHIJUN, Q., QINGFENG, W., XIANFENG, Ch. Application of virtual reality technology in nuclear device design and research. 2020. Fusion Engineering and Design, Volume 161, ISSN 0920-3796, https://doi.org/10.1016/j.fusengdes.2020.111906.

[19] JIANGHAI, L. et al. Using Wireless Sensor Networks to Achieve Intelligent Monitoring for High-Temperature Gas-Cooled Reactor. 2017. Science and Technology of Nuclear Installations, vol. 2017, Article ID 3721578, 8 pages. https://doi.org/10.1155/2017/3721578 https://doi.org/10.1007/s00170-021-07286-x

[20] ATAUL, B., JIN, J. A review of wireless sensor networks for nuclear power plant applications. 2015. International Electronic Journal of Nuclear Safety and Simulation, Volume 6(1), 53-67. ISSN 2185-0577.

[21] JIANGHAI, L., JIA, M., KANG, X., LONG, Z., HUANG, X., Using Wireless Sensor Networks to Achieve Intelligent Monitoring for High-Temperature Gas-Cooled Reactor. 2017. Science and Technology of Nuclear Installations, vol. 2017, Article ID 3721578, 8 pages. https://doi.org/10.1155/2017/3721578.

[22] QI, L., SHIBIAO, X., JU, X., YING. W., Sharp Feature-Preserving 3D Mesh Reconstruction from Point Clouds Based on Primitive Detection. 2023. Remote Sensing. ISSN: 2072-4292, DOI: 10.3390/rs15123155

[23] PARKER, E., et al., Examining the residual radiological footprint of a former colliery: An industrial nuclear archaeology investigation, 2023, Journal of Environmental Radioactivity, ISSN: 0265-931X, DOI: 10.1016/j.jenvrad.2023.107292

[24] ALBY, E., GRUSSENMEYER, P., From point cloud to 3D model, modelling methods based on architectural knowledge applied to fortress of Chatel-sur-moselle (FRANCE), The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences, ISSN: 1682-1777, 2012

[25] HINKS, T., et. al., Point Cloud Data Conversion into Solid Models via Point-Based Voxelization, Journal of Surveying Engineering, Volume 139, p. 72 – 83, ISSN: 0733-9453, 2012, DOI: 10.1061/(ASCE)SU.1943-5428.0000097

[26] WANG, G., ZHOU, B., FANG, B., Fast 3D Object Measurement Based on Point Cloud Modeling, International Journal of Pattern Recognition and Artificial Intelligence, ISSN: 0218-0014, 2023, DOI: 10.1142/S0218001423550133

[27] INTERNATIONAL ATOMIC ENERGY AGENCY. Robots, Drones and Artificial Intelligence for Advanced Decommissioning and Environmental Remediation: Winners of the IAEA 2020 Crowdsourcing Challenge. Online. Accessed 10 May 2021. https://www.iaea.org/newscenter/news/robots-drones-and-artificial-intelligence-for-advanced-decommissioning-and-environmental-remediation-winners-of-the-iaea-2020-crowdsourcing-challenge

[28] SHUICHIRO, O., YU, Y., KOKI, I. Development of a Robot for Decontamination of High Places and Decommissioning Work That Can Cope with Slopes and Steps. 2023., Eletronics. ISSN: 2079-9292, DOI: 10.3390/electronics12112403

[29] ADIBELI, J. O., et. al., Path planning in nuclear facility decommissioning: Research status, challenges, and opportunities, Nuclear Engineering and Technology, Volume 53, Issue 11, November 2021, p. 3505 – 3516, 2021, ISSN: 1738-5733, https://doi.org/10.1016/j.net.2021.05.038

[30] MARTIN, P. G., et al., 3D unmanned aerial vehicle radiation mapping for assessing contaminant distribution and mobility. 2016. International Journal of Applied Earth Observation and Geoinformation, Volume 52, Pages 12-19, ISSN 0303-2434, https://doi.org/10.1016/j.jag.2016.05.007.

[31] C. HACKETT, A. Drones for Radiological Assessment, Reference Module in Earth Systems and Environmental Sciences. 2020. Elsevier, ISBN 9780124095489, https://doi.org/10.1016/B978-0-12-819725-7.00015-5.

[32] RAJENDRAJ, P. K. et al. Implementation and Analysis of MapReduce on Biomedical Big Data. 2016. Indian Journal of Science and Technology. 9. 1-6. 10.17485/ijst/2016/v9i31/83451.

[33] RIAZ, Z., EDWARDS, D., PÄRN, E., SHEN, C., PENA-MORA, F. BIM and sensor-based data management system for construction safety monitoring. 2017. Journal of Engineering, Design and Technology. 15. 738-753. 10.1108/JEDT-03-2017-0017.

[34] WALTON, P., Artificial Intelligence and the Limitations of Information. 2018. Information, Online ISSN: 2078-2489, DOI: 10.3390/info9120332

[35] EL-SEFY, M. et al. Artificial neural network for predicting nuclear power plant dynamic behavior. 2021. Nuclear Engineering and Technology, Volume 53, Issue 10, https://doi.org/10.1016/j.net.2021.05.003

[36] P. SENNA, P. et al. Architecture Model for a Holistic and Interoperable Digital Energy Management Platform. 2020. Procedia Manufacturing, Volume 51, Pages 1117-1124, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2020.10.157

[37] BAJENARU, L., IANCULESCU, M., DOBRE, C., A Holistic Approach for Creating a Digital Ecosystem Enabling Personalized Assistive Care for Elderly. 2018. IEEE 16th International Conference on Embedded and Ubiquitous Computing (EUC), 2018, pp. 89-95, doi: 10.1109/EUC.2018.00020.

[38] SACKS, R. et al. Construction with digital twin information systems. 2020. Data-Centric Engineering. 1. 26. 10.1017/dce.2020.16.

[39] PATTERSON, E., TAYLOR, R., BANKHEAD, M. A framework for an integrated nuclear digital environment. 2016. Progress in Nuclear Energy. Volume 87, pages 97-103. 10.1016/j.pnucene.2015.11.009.

[40] SANJU, M. T., AJITH, A. Semantic assessment of smart healthcare ontology. International Journal of Web Information Systems. 2020. ahead-of-print. 10.1108/IJWIS-05-2020-0027.

[41] BORRMANN, F. et al. An international approach to a decommissioning ontology. 2021. DEM 2021 – International Conference on Decommissioning Challenges: Industrial Reality, Lessons learned and Prospects, France, Avignon

[42] VOLODIN, V. S., TOLOKONSKIJ, A. O. Concept of instrumentation of digital twins of nuclear power plants units as observers for digital NPP I&C system. 2019. Journal of Physics: Conference Series, Volume 1391, 8th International Conference on Mathematical Modeling in Physical Science 26–29 August 2019, Bratislava, Slovakia

[43] INTERNATIONAL ATOMIC ENERGY AGENCY, Data Analysis and Collection for Costing of Research Reactor Decommissioning, Report of the DACCORD Collaborative Project, 2017, International Atomic Energy Agency, Vienna, ISBN 978–92–0–108717–1

[44] INTERNATIONAL ATOMIC ENERGY AGENCY, Data Analysis and Collection for Costing of Research Reactor Decommissioning, Final Report of the DACCORD Collaborative Project, 2021, International Atomic Energy Agency, Vienna, ISBN 978–92–0–108621–1

[45] WORLD NUCLEAR ASSOCIATION, Decommissioning Nuclear Facilities. Online. Accessed September 23, 2022. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx

[46] DANISKA, D., BORRMANN, F., SZOKE, I. BIM-based digital nuclear decommissioning support system. Bratislava, 2021. ELITECH '21, FEI STU

[47] SZŐKE, I. et al., Requirements for the design of the PLEIADES concept, 2021, Project PLEIADES deliverable D1.1

[48] DANIŠKA, D. et al., Specifications for the PLEIADES system prototype and validation tests, 2021, Project PLEIADES deliverable D1.2

[49] BORRMANN, F. et al., Ontology describing a nuclear decommissioning project, 2021, Project PLEIADES deliverable D1.4

[50] COURCHESNE, M., et al., PLEIADES platform software architecture, 2022, Project PLEIADES deliverable D2.1

[51] DANIŠKA, D., et al., PLEIADES software interfaces, 2022, Project PLEIADES deliverable D2.2

[52] DE BIEVRE, N., et al., PLEIADES platform validation tests, 2022, Project PLEIADES deliverable D2.3

[53] Institute for Energy Technology, Halden Virtual Reality Centre, HVRC VRdose System Overview – User documentation. Online. Accessed April 13, 2023. http://www2.hrp.no/vr/vrdose/pdf/vrdose-overview.pdf

[54] Institute for Energy Technology. 3D ALARA Planning & Briefing Software. Online. Accessed 22 June 2021. https://ife.no/en/Service/hvrc-vrdose/

[55] WAI s.r.o. What is AquilaCosting Software? Online. Accessed 22 June 2021. http://www.aquilacosting.com/about-the-software

[56] Cyclife Digital Solutions. The first 3D simulation software dedicated to nuclear projects. Online. Accessed 22 June 2021. http://www.orekasolutions.com/demplusfornuclear/demplusfornuclear_en.html

[57] iUS Institut für Umwelttechnologien und Strahlenschutz GmbH. Über uns. Online. Accessed 12 March 2021. http://www.ius-online.eu/de/Profil

[58] VTT Technical Research Centre of Finland Ltd. ALVAR for Unity. Online. Accessed 16 March 2021. http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/doc/alvar-unity/index.html

[59] JAVYS, a.s. A1 Nuclear Power Plant History. Online. Accessed 13 May 2021. https://www.javys.sk/en/nuclear-facilities/a1-nuclear-power-plant/history

[60] DANIŠKA, D., VRBAN, B., Decommissioning planning: Empowering efficiency through BIM modelling and a single-source-of-truth framework, 2023, Nuclear Engineering and Design, Volume 414, Art. no. 112617 [11] p. ISSN: 0029-5493

[61] DANIŠKA, D., VRBAN, B., NEČAS, V., Development of Database Structures and Data Exchange Principles for Nuclear Decommissioning Planning, Radiation Protection Dosimetry, Volume 198, Issue 9-11, August 2022, Pages 740–746

[62] CHANG, C., Blockchain for Integrated Nuclear Power Plants Management System, Department of Nuclear Power Plant Engineering, KEPCO International Nuclear Graduate School (KINGS), Ulsan 45014, Korea, 2020, https://doi.org/10.3390/info11060282

Own research activities and publications

ADC Scientific works in foreign peer-reviewed journals

1. DANIŠKA, Dušan - VRBAN, Branislav - NEČAS, Vladimír. Development of database structures and data exchange principles for nuclear decommissioning planning. In

Radiation Protection Dosimetry. Vol. 198, No. 9-11 (2022), p. 740-746. ISSN 0144-8420 (2022: 1.000 - IF, Q4 - JCR Best Q, 0.321 - SJR, Q3 - SJR Best Q).

Citation:

1. PING, W., XINGQIAO, W., XIN, Z., ZHIMIN, G. A Method for Data Exchange and Management in the Military Industry Field. 2023. Advanced Data Mining and Applications. ISSN 0302-9743. DOI: 10.1007/978-3-031-46674-8_47

2. DANIŠKA, Dušan - VRBAN, Branislav. Decommissioning planning: Empowering efficiency through BIM modelling and a single-source-of-truth framework. In Nuclear Engineering and Design. Vol. 414, (2023), Art. no. 112617 [11] p. ISSN 0029-5493 (2022: 1.700 - IF, Q2 - JCR Best Q, 0.853 - SJR, Q1 - SJR Best Q).

AFC Published contributions at foreign scientific conferences

1. DANIŠKA, Dušan - VRBAN, Branislav. Utilization of BIM models and ISDC structure for improving nuclear decommissioning cost estimations. In NUPP 2022: 4th International conference on nuclear power plants: Structures, risk and decommissioning. September 19-20, 2022. Glasgow : ASRANet Ltd, 2022, S. 78-81. ISBN 978-1-8383226-8-7.
2. DANIŠKA, Dušan - SEDMÁK, Marek - VRBAN, Branislav. Radioactive hot spot - modeling of dismantling processes coupled with an estimation of costs. In NUPP 2022: 4th International conference on nuclear power plants: Structures, risk and decommissioning. September 19-20, 2022. Glasgow : ASRANet Ltd, 2022, S. 89-94. ISBN 978-1-8383226-8-7.

AFD Published contributions at domestic scientific conferences

1. DANIŠKA, Dušan - SZŐKE, Istvan - BORRMANN, Franz. BIM-based digital nuclear decommissioning support : Current status and research activities in BIM-based digitalization of nuclear. In ELITECH´21 [electronic source] : 23th Conference of Doctoral Students, May 26, 2021. 1. ed. Bratislava: Vydavateľstvo Spektrum STU, 2021, [6] s. ISBN 978-80-227-5098-1
2. DANIŠKA, Dušan. Advances and achievements in R&D project PLEIADES. In ELITECH´22 [electronic source] : 24th Conference of Doctoral Students. Bratislava, Slovakia. June 1, 2022. 1. ed. Bratislava: Vydavateľstvo Spektrum STU, 2022, [3] s. ISBN 978-80-227-5192-6.

AFG Abstracts of contributions from foreign conferences

1. DANIŠKA, Dušan - VRBAN, Branislav – NEČAS, Vladimír. Standardization of the database structures for data and information used in nuclear-decommissioning projects. In XLII. Radiation protection days: collection of abstracts. Online, Czech republic. 8.-12.11.2021. 1. issue. Praha : Czech Technical University in Prague, 2021, S. 74. ISBN 978-80-01-06915-8.
2. JACQUES, Marie-Benedicte – GENTES, Sascha – RIDAO CABRERIZO, Jose Antonio – DANIŠKA, Dušan. The use of digital twins for waste estimation in nuclear facilities’

dismantling and decommissioning: the PLEIADES project. In: Safety of Nuclear Waste Disposal, 2, 11–12, 2023.

Participations on research projects

1. "Development of the software platform for the estimation and optimalization of costs of decommissioning of nuclear installations, based on an international ISDC standard, for achieving safe and effective decommissioning. ", July 2016 - December 2018, funded by Slovak Research and Development Agency, number: APVV-15-055
2. "PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES", October 2020 - September 2023, funded by EURATOM Research and Training Programme 2014-2018 under the Grant Agreement n°899990.

Other scientific works and reports

1. DANIŠKA, Dušan – KRIŠTOFOVÁ, Kristína – BRYNTESEN, Tom-Robert – FRANCOIS, Patrice – LASNIER, Antoine – SALAZAR Mikel – DE BIEVRE, Nicolas – LAUNONEN, Raimo. Specifications for the PLEIADES system prototype and validation tests. 2021. Project PLEIADES deliverable D1.2.
2. COURCHESNE, Martin – DANIŠKA, Dušan – et al. PLEIADES platform software architecture. 2022. Project PLEIADES deliverable D2.1.
3. DANIŠKA, Dušan – SALAZAR, Mikel – BRYNTESEN, Tom-Robert – EDVARDSEN, Svein Tore – KRIŠTOFOVÁ, Kristína – VINCENT, Perrot – BORRMANN, Franz – CLERE, Berangere – HAKKARAINEN, Mika – POMAREL, Mathieu – DELANNAY, Nicolas. PLEIADES software interfaces. 2022. Project PLEIADES deliverable D2.2.

Additional contributions to conferences and meetings

1. DANISKA, D. Overview of a typical engineering cost estimating process in Slovakia. In: Technical Meeting on Costing Approaches for Nuclear Technology Developers. Vienna: International Atomic Energy Agency. March 26, 2019 to March 28, 2019, Ref. No.: EVT1804759

2. DANISKA, D. International Structure for Decommissioning Costing (ISDC) based Software Support for Decommissioning Cost Estimation. In: Workshop on the Cost Estimation and Cost Analysis of Nuclear Projects and Programmes. Idaho Falls, USA. September 30, 2019 – October 3, 2019

3. DANISKA, D. Optimizing waste management cost estimations by simulating real technologies and clearance limits. In: 8th International Conference on Nuclear Decommissioning. Aachen, Germany. November 12, 2019 - November 14, 2019

4. DANISKA, D., DANISKA, V., FAJURALLY, N. and ZUBCAK, P. New advances in

AquilaCosting decommissioning and waste management cost estimation software. In: Workshop on advanced methods for knowledge management, training and education for nuclear decommissioning. In: DigiDecom 2019. Halden, Norway. June 19, 2019 – June 21, 2019

5. DANISKA, D., DANISKA, V., FAJURALLY, N. and ZUBCAK, P. New advances in AquilaCosting decommissioning and waste management cost estimation software. In: Workshop on advanced methods for knowledge management, training and education for nuclear decommissioning. In: 4th Canadian Conference on Nuclear Waste Management, Decommissioning and Environmental Restoration, Ottawa, Canada. September 8, 2019 – September 11, 2019.
6. DANISKA, D. International Structure for Decommissioning Costing (ISDC) based Software Support for Decommissioning Cost Estimation. In: IAEA Workshop on Cost Estimation and Cost Analysis of Nuclear Projects and Programmes, Idaho Falls, USA. September 30, 2019 – October 3, 2019.
7. DANISKA, D. Optimizing waste management cost estimations by simulating real technologies and clearance limits. In: ICOND Conference, Aachen, Germany. November 11, 2019.
8. DANISKA, D. Costing for decommissioning. In: DigiDecom ELINDER 2020, Halden, Norway. March 23, 2020 – March 27, 2020.
9. DANISKA, D. Technical aspects of digital integrated decommissioning support systems and prospects with ISDC based costing. In: DigiDecom 2021, Halden, Norway. Online presentation. March 24, 2021.
10. DANISKA, D. Development of database structures and data exchange principles for nuclear decommissioning planning. In: IDN Biennale Forum, Vienna, IAEA. December 13, 2021 – December 15, 2021.
11. DANISKA, D. Approaches to cost estimating, cost management, and cost control. In: IAEA National Workshop on Planning and Budgeting for NPP Construction and Operation, Tashkent, Uzbekistan. November 01, 2022 – November 04, 2022.
12. DANISKA, D. Dealing with risks, uncertainties, and deviations. In: IAEA National Workshop on Planning and Budgeting for NPP Construction and Operation, Tashkent, Uzbekistan. November 01, 2022 – November 04, 2022.
13. DANISKA, D. Budgeting cases studies, lessons learned from decommissioning projects. In: IAEA National Workshop on Planning and Budgeting for NPP Construction and Operation, Tashkent, Uzbekistan. November 01, 2022 – November 04, 2022.

Sumár

Metóda optimalizácie plánovania vyraďovania jadrových zariadení pomocou holistickej digitálnej platformy s použitím modelov BIM

Digitalizácia vyraďovania jadrových zariadení je ďalším krokom vo zvyšovaní celkovej efektivity plánovania aj riadenia projektov vyraďovania, najmä z pohľadu zvyšovania bezpečnosti a ekonomických aspektov. Avšak, z dôvodu veľkého množstva týchto technológií, veľkej rozmanitosti údajov, ktoré tieto technológie vyžadujú a spracovávajú, vzniká veľká potreba štandardizácie postupov využívania týchto technológií, vrátane spoločného jazyka a spôsobov prenosu údajov. To v konečnom dôsledku znamená aj to, že veľmi dôležitou súčasťou zvyšovania efektivity existujúcich stratégií plánovania vyraďovania sú informačné systémy založené na poznaní (tzv. 'knowledge-centric information systems'), v anglickej literatúre označované ako K-PIM [1].

Softvérové nástroje zameriavajúce sa na špecifickú oblasť plánovania alebo manažmentu vyraďovania sa používajú izolovaným spôsobom. Tieto softvérové nástroje nie sú s ostatnými integrované buď vôbec, alebo iba málo, a to z dôvodu použitia rozličných technológií, na ktorých sú postavené, ako aj z dôvodu nekompatibility dátových štruktúr, s ktorými pracujú. Táto izolovanosť a nedostatočná miera vzájomnej integrácie spôsobujú nízku efektivitu prenosu údajov z jedného softvéru do druhého, alebo aj medzi jednotlivými tímami spolupracujúcimi na plánovaní.

Pre zlepšenie prenosu dát a vedomostí v oblasti vyraďovania, je potrebné tieto softvérové nástroje vzájomne integrovať použitím štandardizovaného rozhrania (API) založeného na vzájomne zrozumiteľnom jazyku – ontológii. V práci demonštrujem výsledky výskumu zameraného na implementáciu digitálnej platformy na podporu vyraďovania s použitím 3D/BIM procesov a popisujem metódu vzájomnej integrácie izolovovaných softvérových nástrojov, konkrétne AquilaCosting a Vrdose, ako je ilustrované na obrázku 4-2. Prezentácia je založená na porovnaní dvoch odhadov nákladov na demontáž vybraného komponentu, konkrétne nákladov pre predbežný plán vyraďovania a nákladov pre detailný plán vyraďovania. V práci bolo preukázané, že použiie tzv. 'common data environment' (CDE) architektúry a s použitím rozhrania pre prenos údajov (API) vybudovaného na základe štandardizovanej ontológie dokáže zvýšiť efektivitu plánovania tým, že prenos údajov medzi predtým izolovanými softvérovými nástrojmi sa zefektívni. V práci boli taktiež diskutované nasledovné konkrétne zlepšenia efektivity plánovania v prípade použitia novej metódy:

- Zvýšenie bezpečnosti pri práci, znižovanie rizík a zlepšenie vyhodnocovania rizík;
- Zlepšenie rozhodovacieho procesu – na základe lepšie dostupných informácií;
- Efektívnejšia citlivostná analýza, zvyšenie ekonomickej efektivity.

V závere práce sú sformulované odporúčania pre ďalšie výskumno-vývojové aktivity v kontexte slovenského jadrového priemyslu, aj s porovnaním výskumno-vývojových aktivít v zahraničí.