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CONTENTS

Generating Market Comments on Stock Price Fluctuations Using Technical Analysis Features

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***Abstract*—Recently, there has been significant interest in techniques for generating market comments from stock prices automatically. However, it takes a multitude of time and effort for analysts to generate full-text market comments from stock prices. In this paper, we propose a method for generating "comments on stock price fluctuations" included in market comments to reduce the workload of analysts. The proposed method learns stock price fluctuations and the corresponding expressions, generates comments, and completes market condition comments by assigning them to prepared canned sentences. So far, this is the result of our previous study [1], and this paper improves the results by adding new features to the training data. The new data to be added to the training data in this paper are "Dow Jones Industrial Average" and "Technical Analysis", both of which are expected to improve the results. Because of our experiments, we found that the features used to generate them are effective and the proposed method can accurately generate market comments.**

Keywords-Generate market comments; Stock price fluctuation; Nikkei Stock Average; Dow Jones Industrial Average; Technical Analysis.

I. INTRODUCTION

Recently, there has been an increase in the use of data in various fields, such as weather, sports, medicine, and finance. However, when the data is large or complex, it is difficult for a person without expert knowledge to understand it, and even if they are experts, it takes time to understand the data and extract the important elements. One method to make effective use of such data is data-to-text technology. This is a technology that expresses the outline of data in text to make it easier for humans to interpret, and it has been gaining attention due to its increased demand recently.

The task of generating market comments from stock price data, which is the subject of this research, is also a type of data-to-text technology. Currently, analysts, who are specialists in researching and analyzing social conditions, etc., generate market comments. They analyze stock prices after they are released and generate market comments. However, it takes a multitude of time and effort for analysts to generate full-text market comments from stock prices. Therefore, in this paper, we propose a method for generating a part of the market comment to reduce the effort required for analysts to generate market comments. Specifically, we extract expressions related to the price movements of stock prices and their fluctuation ranges, and then generate comments by learning the price movements of stock prices and expressions through machine learning. By applying the generated comments to the pre-prepared format, the system automatically generates the quantitative analysis results in the market comment, and as a result, analysts can concentrate on their core business, such as factor analysis.

In this paper, we extract various features from the time series data and convert them into text based on the task of generating market comments on the Nikkei Stock Average. First, we form long-term and short-term time series data to capture the changes in the time series stock price data. Next, we extract 12 important phrases from NQN (Nikkei Quick News) so that we can generate an expression in NQN. These phrases are frequent occurrences in the first sentence of the market comment, and the four main expressions are "続落(continued to decline)", "続伸(continued to rise)", "反発(rebound)", and "反落(reactionary fall)", with "大幅(large)" and "小幅(small)" added for 12. Table I shows the details of the phrases. By mapping these expressions to the price movements of stock prices, we create a single data set for learning.

In our experiments, we used the F-measure to compare the phrases generated using the trained data and the phrases extracted from the actual handwritten articles, and we could confirm that the performance of the proposed method was improved compared to the baseline method and those of the previous studies.

So far, this is the result of our previous study [1], and this paper improves the results by adding new features to the training data. The new data to be added to the training data in this paper are the "Dow Jones Industrial Average" and "Technical Analysis." The "Dow Jones Industrial Average" is often mentioned in the text of market comments, and since most of them are involved in the fluctuation of the Nikkei Stock Average, we adopted it as the training data because we consider that it improves the accuracy of the data. Technical analysis is a type of stock price forecasting that has been used recently, and the use of technical analysis in stock price forecasting by machine learning is useful in studies of the impact of technical analysis on machine learning [2]. The difference from using the Dow Jones Industrial Average is that two types of stock prices are used, and one type of stock price is extracted and used, and the accuracy of each type of stock price is checked to see how much the accuracy increases compared to the basic one.

In this paper, as in previous studies, we unified similar expressions among those generated to compare the results with those of a previous study by Murakami et al. [3]. Additionally, sentences that did not require automatic generation by the neural network were omitted. In the future, we will verify whether there are any changes in the experimental results.

TABLE I. Nikkei Stock average.

Phrase	Expression
続伸(continued to rise)	The stock price goes up continuously.
続落(continued to decline)	The stock price falls continuously.
反落(reactionary fall)	The stock price, up, goes down.
反発(rebound)	The stock price, down, goes up.
大幅/小幅続伸	Large or small / continued to rise
大幅/小幅続落	Large or small / continued to decline
大幅/小幅反落	Large or small/reactionary fall
大幅/小幅反発	Large or small / rebound

II. RELATED WORK/METHODS

In this section, we present related work and methods that this paper referred to.

A. *Related works*

Various studies have been conducted on data-to-text technology, which automatically generates a summary of time-series data in easy text for humans to interpret. For example, research has been conducted to automatically generate text about weather forecasts from time-series weather information [4], to generate text from clinical data to assist doctors and nurses in decision-making [5], and to generate feedback text for students from time-series data that records their learning status within a certain period [6].

In the past, the mainstream of data-to-text research has been the generation of text using manually created rules or a machine learning model using various linguistic features [7][8]. Traditional approaches for data-to-text generation implement three components: (1) content planning that selects content from input data, (2) sentence planning that decides the structure and lexical content of each sentence, (3) surface realization that generates the final output by converting the sentence plan [9]. However, recently, with the development of information and communication technology, large-scale and complex data have become readily available, and interest in machine-learning type methods that generate text based on large-scale correspondence between data and text has been increasing. For example, research has been conducted on the use of machine learning in various data-to-text techniques, such as image caption generation [10], which generates descriptions from image data, and weather forecast text generation from molded weather data [11].

B. *Related methods*

Techniques for generating market comments can be approached from various perspectives. For example, there are techniques to generate factors of change, such as events that are said to have affected the price movement of the Nikkei Stock Average and information on other stocks [12], to control the generated text by inputting topics representing the content of the generated market comment in addition to the Nikkei Stock Average data [13], and to generate characteristics, such as the history of the price of the stock and time-dependent expressions [3].

III. TASKS FOR SIMPLE WORD GENERATION

In this paper, we are working on a technique to generate text by appropriately selecting words representing the direction of price movement and the range of fluctuation of stock prices. The task is not a traditional full-text generation task, but a word generation task, which is easy to implement and can be expected to yield good results. In the previous research on the market comment generation task, expressions related to stock price fluctuations have been generated in the process of generating market comments, but there has been no research on generating expressions related to fluctuation ranges such as large or small, which has a novelty. Furthermore, the current market comments in NQN are generated by analysts in about 10 minutes even in a short period, but this research will make it possible to generate simple market comments in real-time.

In market comments, not all expressions written at the same time of stock price fluctuations are the same. For example, Table II shows that a market commentary on one-day notes “続伸(continued to rise)” but on another day with the same fluctuation range, it may not "小幅続伸 (Slight increase)”. (XX is the same number, or there is a small margin of error.)

TABLE II. Example of the same fluctuation range but with different expressions.

Text	Expression
日経平均大引け、続伸終値は XX 円高の ZZ 円 (Nikkei 225 closing continuing to rise. The closing price was XX yen higher at ZZ yen.)	続伸(continued to rise)
日経平均大引け、小幅続伸終値は XX 円高の ZZ 円 (Nikkei 225 closing slightly higher. The closing price was XX yen higher at ZZ yen.)	小幅続伸 (Slightincrease)

One factor that could cause the expression to change for the same fluctuation range is the size of the previous day's fluctuation range. Other factors that could be considered include large fluctuations in stock prices other than the Nikkei Stock Average or a change in the analyst's sentiment based on information obtained from their analysis. This study focuses on the need to consider stock prices other than the Nikkei Stock Average and analysts' sentiments, etc., rather than simply following a rule-based approach where the previous day's fluctuation range determines the market comment generated, and therefore, by using machine learning to analyze big data, we are attempting to generate expressions that are not influenced by analysts' sentiments.

TABLE III. The main text of NQN.

	7 日の東京株式市場で日経平均株価は続落した。終値は前日比 94 円 51 銭（0.59%）安の 1 万 5814 円 37 銭だった。 (The Nikkei Stock Average continued to fall on the Tokyo Stock Exchange on August 7. The closing price was ¥15,814.37, down ¥94.51 (0.59%) from the previous day.) 前日の米株安や外国為替市場で円安・ドル高の流れが一服しているのを受けて売りが優勢だった。 (Selling was dominated by the weak U.S. stock market on the previous day and a lull in the trend of yen depreciation and dollar appreciation in the foreign exchange market.)

IV. VALIDITY OF U.S. STOCK PRICES

In this paper, we use the "Dow Jones Industrial Average," an American stock price index, in addition to the training data from previous studies.

The "Dow Jones Industrial Average" is an American stock price index that uses the same calculation method as the Nikkei Stock Average. In this paper, NQN headlines are used as article data; the Dow Jones Industrial Average has been added as additional stock price data because the word "U.S. stocks" referring to the Dow Jones Industrial Average appears frequently in the text of the NQN. Examples are shown in Table III. The word "米株(U.S. stock)" appears with a probability of about 60% in the data of all articles covered in this study and is considered to have a large effect on the sentences or words before and after the article. The expression representing the fluctuation of the Nikkei Stock Average, which is a word generated in this study, is an example of such an expression, so this study confirms the effectiveness of using U.S. stock prices as training data. As shown in the table, the Dow Jones Industrial Average stock price is often expressed as "low" or "high," and few statements mention the Dow Jones Industrial Average stock price. Therefore, instead of adding the numerical value of the U.S. stock price to the training data, two values indicating whether the stock price was high or low were added to examine how this affected the results.

V. STOCK PRICE FORECASTING USING TECHNICAL ANALYSIS

In this paper, technical analysis, which is used to forecast stock prices, is used in addition to the study data from previous studies. Technical analysis is the process of predicting stock prices by identifying trends and patterns based on past stock price movements. The results obtained from the analysis are called technical indicators. For example, if there has been a similar pattern of stock price fluctuation in the past, there will likely be a similar pattern in the future. 15 factors of technical analysis are used in the paper [2] introduced in Section I to construct a model to predict stock prices. The actual model predicts whether the stock price fluctuation will increase or decrease on the next day using the stock price fluctuation and the factors obtained from technical analysis. However, what is predicted in this paper is not the stock price fluctuation, but the expression of the market comments generated by the stock price fluctuation. Technical indicators were employed because once it is known whether the stock price is going up or down, an accompanying expression can be generated.

Two technical indicators were used: the psychological line and the momentum indicator. Although these two types are unrepresentative of the technical indicators used, they were chosen for ease of implementation. The results of using one of each of these two types of indicators as well as the results of using the two types of indicators as factors will be used to confirm whether the factors are valid or not.

A. Psychological line

The psychological line is a quantification of the investor's truth. More and more investors will judge that a stock price that has risen consecutively has an increased likelihood of falling. The indicator that quantifies this investor psychology is the psychological line. The calculation method is based on the number of days in a calculation period (generally 12 business days) on which the stock price rises as a percentage, regardless of the rate of fluctuation of rises and falls. Generally, the stock tends to be undervalued when the winning rate (rate of increase) is 25% or less and overvalued when the winning rate (rate of increase) is 75% or more. In this paper, we divide the calculation period, which is usually 12 business days, into 3, 6, 9, and 12 periods to see which period gave better results.

B. Momentum

This is a technical indicator that evaluates the momentum of the market. It is calculated by subtracting the closing price of a certain number of days back from the closing price of the day. The most used days are 10, 20, and 25 days. In this paper, we use 10 days. A larger positive value indicates a stronger market, and a larger negative range indicates a weaker condition.

C. Other technical indicators

Here are some other typical technical indicators used to predict stock prices that were not used in this study.

RSI is an indicator to determine whether the market is overbought or oversold based on the ratio of the rate of the price increase. Generally, when the ratio is below 30%, it is considered oversold and the stock price often improves, while when the ratio is above 70%, it is considered overbought.

MACD is an indicator that uses moving averages. It is plotted on a technical chart and determines when to buy and sell based on the movement of the short-term moving average and the medium- and long-term moving averages.

VI. PROPOSED METHOD

In this section, we present a method for extracting words and phrases representing the price movement and fluctuation range of stock prices from the Nikkei Stock Average and NQN and the data used in this paper.

A. Overview

Figure 1 shows the execution procedure of the proposed method.

First, we molded the data to create a correspondence between stock price and article data. Since the article data contains many noisy expressions, we set the conditions to remove the noise and extract the original phrases of the expressions generated from the article data. Details will be described later.

Next is the stock price data, which also contains a multitude of noise and is inefficient for machine learning, so we molded it into a form that is easy to learn.

We then created a correspondence between three days of stock price data and a single expression and used it to start learning. For machine learning, we used a Multilayer Perceptron (MLP), which is commonly used as an encoder.

Finally, using the trained data, we predict phrases by inputting test data containing the Nikkei Stock Average, Dow Jones Industrial Average data, and technical indicator data. The generated phrase is substituted into the prepared format to complete the market comment. However, the generated phrase is used as the evaluation criterion in this paper, and it is not compared with the full text assigned to the format.

B. Pre-processing

In various fields, such as image processing and natural language processing, it is common to perform preprocessing to generalize machine learning models and to remove noise from data. Also in this paper, preprocessing is applied to the Nikkei Stock Average data, which is numerical data. We used the standardization and difference from the previous day as the preprocessing methods for the numerical data. The equations of the processing methods are given below.

$$x_{std} = (x_i - \mu)/\theta \quad (1)$$

$$x_{move} = x_i - r_i \quad (2)$$

x_i denotes the stock price.

In (1), standardization is performed using the data x, mean value μ, and standard deviation θ used for learning.

Equation (2) calculates the difference between the price x_i at each time step from the previous day's closing price $r_i$to capture the change in price from the previous day's closing price.

As in previous studies [1][3], we prepared short-term time series data to capture both short-term and long-term stock price fluctuations: daily stock price data "XShort" consisting of 62time steps, and long-term stock price data "XLong" using past closing prices as input.

However, it is difficult to extract the expressions of short-term data from the articles. This is because the number of market commentaries including expressions on stock price fluctuations is not sufficient for the 62 pieces of short-term data. Furthermore, the number of market commentaries generated in a day is also different, making it difficult to map the data. Additionally, we generated expressions corresponding to the short-term stock price data based on the long-term stock price data and attempted to generate expressions on the training data, but the generation rate did not exceed that of previous studies, so the results

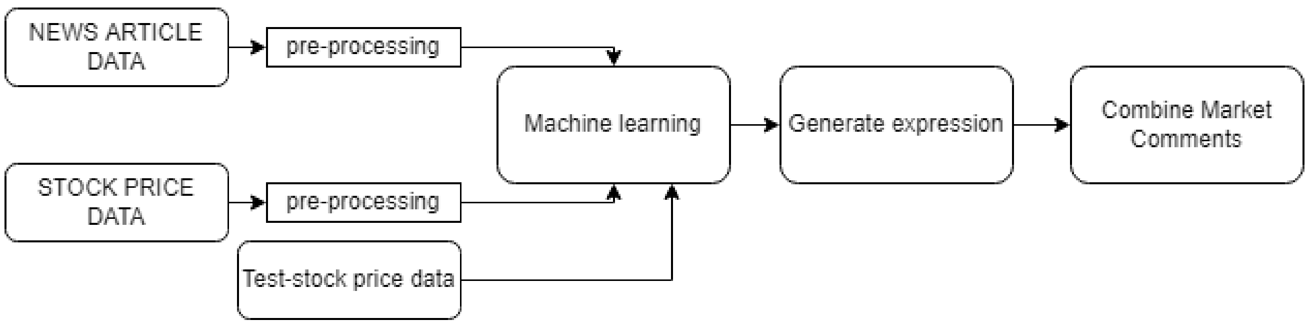

Figure1. Overview. NQN is used for article data, and the Nikkei Stock Average and Dow Jones Industrial Average are used for stock price data. Each model is preprocessed, and three models are created and trained. When combining the Dow Jones Industrial Average and technical indicators as features, the models are added to X_move_std. Note that in this study, the "Combine Market Comments" part is not considered, but the expressions generated by the "Generate expression" are compared.

are omitted from this paper, which shall deal mainly with the long-term stock price data. The long-term stock price data is composed of the closing price of the Nikkei Stock Average, and since the market commentary of NQN, which summarizes the day, is generated around 15:00, just when the closing price is about to be released, it is appropriate to link the stock price with the article to create the training data. Three xstd features and two xmove features are extracted from three days of stock price data, combining a total of five features and one expression.

The preprocessing of article data is performed in the following order:

1. Collect article data for the period related to the stock price data. The period data to be collected is the closing price (15:00). However, since not all articles are posted at exactly 15:00, a one-hour threshold is set.

2. Select the article written at the earliest period among the collected article data and extract the expressions in the article. The expressions extracted are converted into appropriate numbers for machine learning.

C. Dataset

In this paper, we use the Nikkei Stock Average, technical indicator, and the Dow Jones Industrial Average as stock price data and NQN as article data. The data used are for the four years from 2014 to 2017. Tables IV and V show examples of the Nikkei Stock Average and the Dow Jones Industrial Average used in this paper. Table VI shows the values for Table IV with the B preprocessing applied, and these three types of data are treated as training data to check their validity. Table VII shows the dataset with the addition of U.S. stocks. The Dow Jones averages are added only to Xlong_move_std, not to all three types. Table VIII shows the dataset with the addition of technical indicators.

TABLE IV. Nikkei Stock average.

date	**Price (close)**
2014/1/6	15908.88
2014/1/7	15814.37
2014/1/8	16121.45

TABLE V. Dow Jones Industrial Average.

Date	**Price (close)**
2014/1/6	16425.09
2014/1/7	16530.90
2014/1/8	16462.69

TABLE VI. Pre-processed data.

Training Data	Move-prev	Move-today	Std-pprev	Std-prev	Std-today
Xlong_move	-94.51	307.8			
Xlong_std			0.449250	0.354595	0.662144
Xlong_move_std	-94.51	307.8	0.449250	0.354595	0.662144

TABLE VII. Dataset with the addition of U.S. stocks.

Training Data	Training Data (Dow Jones)	expression
Xlong_move	-	rebound
Xlong_std	-	
Xlong_move_std	1	

TABLE VIII. The dataset with the addition of technical indicators.

Training Data	Train Data (Tech indicator)	expression
Xlong_move	-	rebound
Xlong_std	-	
Xlong_move_std	Psy Line or Mom	

D. Encoding

Generally, MLP, CNN, and RNN are considered encoding methods for time series stock price data. However, from the results of previous studies, the model using MLP as an encoder produces better scores than all other models, including the baseline. Therefore, MLP is also used as an encoder in this study.

VII. EXPERIMENT

Table IX compares the dataset used in the previous study with the dataset used in this study. The comparison with the previous paper is made only where the expressions are covered. The reason for the difference in the data used in the training data is that the data of the Nikkei Stock Average for 2013 was in a different format from the data of other years, making it difficult to extract the data. Although there are some differences between the Nikkei 225 data of 2013 and 2017, the differences have been compensated for by increasing the number of train data. Additionally, the test data are all the same, so the results are expected to be fine.

All the technical indicators used in this study refer to stock price values from the previous day or later, which makes a difference in the number of training data. For example, in the case of the Psychological Line, the indicator is calculated by referring to stock prices up to 9 days before the target date. In this case, the target date is the 10th day or later, so the number of training data differs. The same can be said of momentum. Regarding training data, each model is the result extracted from 3 years of stock price data, and differences in the size of the training data are not considered.

TABLE IX. Dataset for the previous paper and this paper.

	Previous paper	**This paper**
Training data	Nikkei Stock Average/ NQN in 2013,2014,2015	Nikkei Stock Average/ NQN in 2014,2015,2017
test data	Nikkei Stock Average / NQN in 2016	Nikkei Stock Average / NQNin 2016
Expressions that describe changes in stock prices	10/Four expressions were used as references for comparison with this study	12

VIII. RESULT

In this section, we present the results when the Nikkei Stock Average is used as the input and when both the Nikkei Stock Average and the Dow Jones Industrial Average are given as the input.

A. Result: Only using Nikkei Stock Average

In this experiment, we use a combination of time series data Xlong and Xshort and preprocessing methods std and move, with one-time series data as a reference and one or both preprocessing methods applied to it. The number of expressions used in the previous study was four, and they are shown in Table X. Table X includes the experimental results. The results in the previous study column refer to the method that produced the highest F value. The red letters represent the best results within Xlong. The blue letters are the ones with good results, but without the expression for the stock price fluctuation range. This is because when generating comments, NQN does not produce expressions at the five-minute version, so we used a rule base to generate expressions without stock price fluctuation ranges. Although it is not directly related to the experimental results, it is described following the execution results of previous studies. If only generating expressions within market comments, the overall results are better when using Xlong's model as training data than in prior studies.

Comparing within xlong, Xlong_move_std is the best model if only the number of occurrences is used (Xlong_move: Xlongstd:Xlong_move_std=7:8:9 (ratio of appearances)).

B. Result: Using the Nikkei Stock Average and the Dow Jones Industrial Average

In this section, results are compared when Dow Jones averages are given as the input values when creating the training data. The comparison will be made with Xlong-move-std, which had the best results in result A. Since the training dataset was modified when the Dow Jones Industrial Average was given as input, and a different F value was calculated than in result A. Table XI includes the experimental results. The results show that although some results are worse than those of the previous studies, the overall F value has increased. Compared to Xlong, the f-values of the four main expressions have not changed much, but the f-values of the expressions representing the fluctuation range have improved.

C. Result: Using Nikkei Stock Average and technical analysis

In this section, a comparison of results was made when technical indicators were given as input values during the creation of the training data. Comparisons were made with Xlong-move-std and with technical indicators results.

First, the psychological lines were added to the training data. Table XIII gives the f-score for each calculation period for the psychological line. The results show that the best results were output for 9 days rather than the standard 12-day period. These results are shown, but only the standard 12-day results are significantly worse, and after a certain calculation period, they all calculate the same f-score. Therefore, the 9-day psychological line was used in this study instead of the 12-day psychological line, which is set by default.

Next, momentum was added to the training data. The momentum is calculated by subtracting the closing price 10 days before the target date, but since the value it is not suitable for machine learning, std preprocessing was applied. Table XII contains a comparison between xlong_move_std plus psychological lines, momentum, and xlong-move-std.

TABLE X. Result: Only using Nikkei Stock Average.

Expressions	Xlong_move	Xlong_std	Xlong_move_std	Xshort_move	Previous study
Rebound	0.9	0.85	0.91	0.98	0.803
Reactionary fall	0.94	0.90	0.90	0.98	0.748
Large reactionary fall	0.62	0.38	0.60	-	-
Large rebound	0.55	0.60	0.44	-	-
Large continued to decline	0.00	0.77	0.00	-	-
Large continued to rise	0.60	0.69	0.63	-	-
Small, rebound	0.00	0.00	0.00	-	-
Small,reactionary fall	0.00	0.00	0.00	-	-
Small. continued to rise	0.00	0.00	0,46	-	-
Small, continued to decline	0.00	0.00	0.50	-	-
Continued to rise	0.90	0.89	0.88	1.00	0.814
Continued to decline	0.89	0.87	0.90	1.00	0.753

TABLE XI. Result: Using Nikkei Stock Average and Dow Jones Industrial Average.

Expression	Xlong_move_std	+Dow	Previous
Rebound	0.91	0.78	0.803
Reactionary fall	0.90	0.84	0.748
Large reactionary fall	0.60	0.18	-
Large rebound	0.44	0.67	-
Large continued to decline	0.00	0.73	-
Large continued to rise	0.63	0.38	-
Small, rebound	0.00	0.00	-
Small, reactionary fall	0.00	0.00	-
Small. continued to rise	0,46	0.40	-
Small, continued to decline	0.50	0.29	-
Continued to rise	0.88	0.89	0.814
Continued to decline	0.90	0.71	0.753

TABLE XII. Result: Using the Nikkei Stock Average and technical analysis

Expression	Xlong_move_std	+PSY	+MOM
Rebound	0.91	0.83	0.87
Reactionary fall	0.90	0.95	0.92
Large reactionary fall	0.60	0.00	0.67
Large rebound	0.44	0.36	0.29
Large continued to decline	0.00	0.00	0.00
Large continued to rise	0.63	0.00	0.00
Small, rebound	0.00	0.00	0.00
Small, reactionary fall	0.00	0.44	0.29
Small. continued to rise	0,46	0.00	0.00
Small, continued to decline	0.50	0.00	0.00
Continued to rise	0.88	0.83	0.87
Continued to decline	0.90	0.83	0.85

TABLE XIII. F-score for each calculation period for the psychological line.

calculation period	f-score
12	0.695
9	0.744
6	0.721
3	0.724

IX. DISCUSSIONS

In this section, we will discuss the results.

A. *Expressions about stock price fluctuations and Xshort.*

NQN does not produce expressions every 5 min, but only for important periods (9:00, 12:00, 15:00). Therefore, in the case of short-term data that deals with five-minute data, it is necessary to extract expressions mechanically or by using other data as training data and extracting expressions by predicting them. In this paper, the former method was used. In producing the expressions for short-term data, we used the difference from the previous day in two steps. Specifically, two steps of the previous day's difference are used, with a positive value indicating "続伸(continue to rise)" and a negative value indicating "続落(continue to decline)". However, the thresholds for large or small at this time are not defined, resulting in the results shown in Table V. The NQN shows several instances of large and small falls, but the conditions for their appearance could not be determined because of only two steps of difference from the previous day, so it was impossible to set a threshold. The reason for this is that the analysts who write the market commentary assign "large" and "small" according to their sensitivity.

Therefore, the results show a high F value because there were only four expressions for three years of data. One of the future tasks will be to determine the threshold for mechanically generating expressions related to the range of fluctuation. Another possible method of generation is to create training data with long-term stock price data, predict the expression of short-term stock price data from it, and then create new training data from it. However, when this method was used simply before, the results were much lower than when the long-term stock price data was used as training data, so the method needs to be considered.

B. *Extraction methods were considered based on differences with previous studies.*

Table XIV shows the comparable areas in this paper and previous studies. This study produced high F values for all comparable expressions. This is thought to be because similar expressions in the previous studies, such as "反発(rebound)" and "上げに転じる(start to move up)", were treated as the same in this study. To improve the accuracy of expression generation, we unified the expressions in this study. It was found that unifying the expressions increased the accuracy by about 10-20%. Instead, the fluency of the sentences has been reduced. However, since there are no clear rules on how to use words such as "反発(rebound)" and "上げに転じる(start to move up)" that occur in market conditions, it is best to unify them.

TABLE XIV. Comparison of previous studies and this study.

Expression	This Paper	Previous paper
Continued to decline	0.91	0.803
Continued to rise	0.90	0.748
Rebound	0.88	0.814
Reactionary fall	0.90	0.753

C. *Number of expressions and number of data*

References

The results show that there are some expressions whose occurrence rate is 0, and the problem is that the number of data is too large for the number of expressions prepared.

The following is a table of the number of expressions that exist in the data (Table XV) and the occurrence rate of the expression that represents the fluctuation range of stock prices in the data used (Table XVI). The red letters in Table VIII and Table IX are the three selected from the lowest values. Looking at Table IX, we can see that several expressions are never generated. As in the case of Short, if the training data is biased, the result will be like this, so it is desirable to have training data where all expressions are generated to some extent. Or it is necessary to review the expressions to be extracted.

TABLE XV. The number of expressions that exist in the data.

Expression	Xlong_move_std F-value
Continue to rise	184
Rebound	150
Reactionary fall	147
Continue to decline	111
Lage rebound	24
Large, continue to decline	24
Small continue to decline	20
Large Reactionary fall	17
Small continue to rise	17
Small reactionary fall	14
Large continue to rise	13
Small rebound	8

TABLE XVI. Occurrence rate of the expression that represents the fluctuation range.

Expression	Xlong_move_std F-value
Large rebound	0.6
Large reactionary fall	0.44
Large continue to rise	0
Large continue to decline	0.63
Small rebound	0
Small reactionary fall	0
Small continue to rise	0.46
Small continue to decline	0.5

D. Effects of the Dow Jones Industrial Average

The market comments published in NQN often mention the fluctuation of the Nikkei Stock Average in the first line, and the Dow Jones Industrial Average in the second line or after the second line. In these comments, a sentence like "The Nikkei Stock Average rebounded following the trend of major stock indexes all rising in the U.S. stock market the previous day." appears. As this sentence indicates, Nikkei Stock Average is strongly influenced by the U.S. stock market (Dow Jones Industrial Average), so in this paper, we tested the effectiveness of the phrases. As a result, the F values of the four main phrases (continuous decline, continuous growth, rebound, and decline) stayed almost the same, but the generation rates of the expressions with small and large amounts of percentages increased as a whole. The reason is thought to be that the input of not only the Nikkei Stock Average but also the Dow Jones Industrial Average values resulted in a detailed separation of the expressions related to stock price fluctuations. As in the case of the Dow Jones Industrial Average, we consider whether the results will be further improved or worsened by providing new numerical data affecting the Nikkei Stock Average as an input.

E. Effects of the Technical indicators

Technical indicators are effective in predicting stock prices, and we speculated that if it is possible to predict stock prices, it would also be possible to predict the fluctuation rate associated with them, so we added them as training data. The difference between the Dow Jones Industrial Average and technical indicators as additional data is whether they are composed of only the Nikkei Stock Average or whether they are composed of additional stock prices other than the Nikkei Stock Average. This paper confirms how those differences affect the generation rate of the expression. The results showed that the psychological line was not as effective in improving the results, and the momentum was not as effective as when the Dow Jones Industrial Average was added. In other words, it was found that training data consisting only of the Nikkei Stock Average did not produce good results. However, the technical indicators applied in this paper were prioritized for ease of implementation, and major technical indicators such as MACD and RSI were not implemented. It is recommended that these technical indicators be implemented and compared again. Additionally, although the technical indicators were added one by one to xlong_move_std this time, it is considered that the results may be improved by multiplying technical indicators with each other, just as move and std are multiplied with each other.

X. CONCLUSION

In this paper, we extracted expressions related to the price movements of stock prices and their fluctuation ranges using the Nikkei Stock Average and NQN, learned the expressions and price movements by machine learning, and generated expressions for given stock prices. We compared the generated expressions with those extracted from the original article and verified which training data were superior in terms of correct answer rate and F value.

In conclusion, the results of the training data with two types of preprocessing implemented exceeded those of the previous study. This is thought to be due to the unification of similar expressions in the previous study.

In addition, when generating expressions related to the range of variation of values, such as "大幅(Large)" and "小幅(Small)," it turned out to be difficult to generate them unless the training data contained these expressions with a certain degree of probability.

To examine the influence of the U.S. stock price on the Nikkei Stock Average, we also examined whether there was any change in the generation rate by giving the U.S. stock price (Dow Jones Industrial Average) as a new input. As a result, when the U.S. stock price was given as an input, the generation rate of the main phrases was not significantly affected, but the generation rate of phrases describing the fluctuation range of the stock price was generally improved.

As an additional experiment, a comparison was made between the training data consisting only of the Nikkei Stock Average, including the additional data, and the Nikkei Stock Average with the Dow Jones Industrial Average added.

The additional data were technical indicators, used to predict stock prices. As a result, the accuracy was improved, although not as much as that of the Dow Jones Industrial Average. Further improvement can be expected by using the major technical indicators and by multiplying technical indicators with each other.

Future challenges include setting thresholds to mechanically generate expressions related to the range of variation, creating better training data, revising expressions, and new input values.

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New Technologies in Human-Driven Professions: The Impact of Digital Transformation for Tourist Guides

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***Abstract*—Qualified tourist guides are professionals in cultural, technical, and scientific mediation and they work mainly in public spaces, museums, and historical monuments. The digital transformation of the 2010s has revolutionised the approach to knowledge and has led to a change in the role of qualified tourist guides. By this we mean the explosion of Wikipedia and social networks, as well as the introduction of multimedia in museums. The effects of the current health crisis (Covid) have been added to all this to impose profound changes and irreversible developments. Our reflection is about, on one hand, the way in which the qualified tourist guides can rely on digital technology during a tour and, on the other hand, the new skills that student guides must acquire during their scholarship. We seek to understand where and how digital technology can be an ally of qualified tourist guides without replacing them. We will rely on the professional degree of qualified tourist guides (in French: *guides-conférenciers*), prepared in our Gustave Eiffel University, as well as on our connections with the National Federation of Qualified Tourist Guides, to analyse the digital approach of future professionals in the sector. We also propose perspectives for future works.**

Keywords – Tourist Guide; digital tools; cultural mediation; museums; situational iceberg.

I. Introduction

Since 2010, the tourism sector has been facing a profound digital transformation and has also hit the shock of a health crisis. This is particularly true for qualified tourist guide's profession [1]. We propose to analyse the evolution of the profession of qualified tourist guide, or in French *guide-conférencier* [2], in the global context of digital transformation and Covid pandemic. The digital transformation represents both a threat and a great opportunity for the profession in the perspective of J. Ellul's "ambivalence of technology" analysis [3]. A threat because, as we shall see in Section III, it can be seen as a new competitor to the tour guides as long as the digital replaces the human. At the same time, digital transformation becomes an opportunity to develop new skills to broaden the scope of business or to increase one's own customer base.

After an introduction (Section I), we explain our scientific positioning (Section II), our methodology (Section III) and we give an overview of human mediation (Section IV). Then, we outline the use of digital new tools in the mediation (Section V). Finally, we analyse the future of qualified tourist guides facing Information and Communication Technology (ICT) (Section VI) and we give a conclusion with perspectives for future works (Section VII). Observing our students over the last few years and following the experience of a qualified tourist guide, we realised that it became necessary to re-think the profession of tourist guide by integrating digital tools. Through their master's dissertations and their internships, our students reflect on how to integrate digital tools in their job. We intend to analyse their approach of this subject during their studies and also after, when they will start to work. We want to understand in which way digital technology can be an ally of a qualified tourist guide and will try to provide an overview of the current situation.

The decree n. 2011-930 of August 1st 2011, relating to persons qualified to conduct guided tours in museums and historical monuments [4], has modified the status of the qualified tourist guide. From now on, the law recognises only one professional figure that groups together the four professions that existed until 2011 (regional guide-interpreter, national guide-interpreter, guide-lecturer of the Cities and Countries of Art and History, national lecturer): the qualified tourist guide or in French *guide-conférencier*. Obtaining the professional license (Fig. 1), which is valid throughout France, is subject to the validation of a professional bachelor's degree or a master's degree if the following courses units have been validated: tourist guide skills, professional practice, and modern foreign language. The professional bachelor's degree is characterised by its multidisciplinary approach. The bachelor's degree proposed at the Gustave Eiffel University, for example, focuses on three fundamental aspects: history of art, cultural heritage and general knowledge; practical aspects with guiding techniques and oral mediation of the public; professional aspects of communication, marketing and occupational integration. The aim is to provide students with tools allowing to deal with any type of situation and being able to practice their profession independently or in collaboration with tourist offices and other tourist or cultural establishments, as well as connecting and networking with professionals of the National Federation of Qualified Tourist Guides [5].

The profession of qualified tourist guide is in constant evolution. It requires constant adaptation to the various audiences and the context or subject of the visit. This is especially true with the arrival of new technologies in the 2010s, which have revolutionised the approach to knowledge and have led to a change in the role of the qualified tourist guides. Three stages in the evolution of the profession of qualified tourist guide allow us to better understand its link with the evolution of the Information and Communication Technology (ICT). The first one is about the operating mode of the mediation of the public in general and is related to the evolution of public's expectations. The second is more specific to the content of the tourist guide's presentation, which has evolved with the availability of online information. The last stage combines the two previous ones, gathered in the digital solutions developed in the field of public mediation.

In the following sections, we will detail these three stages in order to understand how the profession of qualified tourist guide must evolve and adapt to the new socio-cultural context. We will analyse the context of the professional bachelor's program of *Guide-Conférencier* at Gustave Eiffel University, and more specifically the relationship of future guides to the digital world. These analyses will be carried out using an information and communication sciences approach.

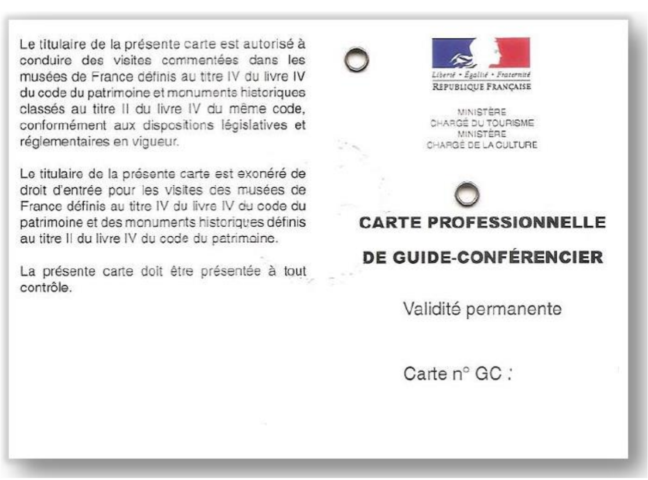

Figure 1. Exemple of profesionnal license for qualified tourist guides. Credits: photo taken on the website of Ancovart https://www.ancovart.fr/la-profession/reglementation

II. Scientific positioning: convergence between link, meaning action and knowledge

This communication associates two teacher-researchers, one in information and communication sciences, the other in computer science, a research engineer working on cultural heritage and a qualified tourist guide, teacher in the same University. They constitute a large part of the supervision and teaching staff of the *Guide-Conferencier* professional bachelor's degree at Gustave Eiffel University. This work is placed in a perspective of research-action and transdisciplinarity, with the construction of knowledge for action starting from new uses of socio-technical devices.

Our scientific position is in the field of information and communication sciences (Fig. 2), within a research team: DICEN-IdF (Information and Communication Devices in the Digital Era). We therefore have an approach that integrates the dimensions of communication (exchanges, interactions), uses and production of data and the use of socio-technical devices. We position according to F. Bernard [6] insisting on the convergence of link, meaning, action and knowledge.

Our work is mainly action research, in particular to analyse activity situations, with the dimension of social constructivism: construction of social reality by the actors. We thus integrate the "situational and interactionist semiotics" approach proposed by A. Mucchielli [7], with the dimension of feelings, emotions and the body as social media, as proposed by F. Martin-Juchat [8], which is particularly important in times of health crisis.

From a methodological point of view, we are depending on the context, in situations of "participant observation", but more often in "observer participation", by being very involved in the follow-up of students in professional situations or in professional activities (all range of touristic and cultural structures).

This double positioning, which is also a positioning of theoretical reflection and strong practical involvement, allows us to be particularly proactive in a reflection on the employability of new graduates and the evolution of this profession of mediation for the development of cultural and tourist heritage in the territories. In an approach of economic and territorial intelligence (Bourret-Fabry-Da Re, 2020 [9]), we insist on the reliance (links, interactions) to participate in the resilience of territories, in the double context of digital transformation and health crisis. As in idea to search for new ways in Competitive or Economic Intelligence [10].

Reliance and resilience by insisting on the informational and communicational stakes of activity situations, to improve the added value and employability of the qualified tourist guides for a better adaptability to meet the expectations of new audiences, and to be much more active in their stays and visits and much more sensitive to the authenticity of the territories and to personalised experiences.

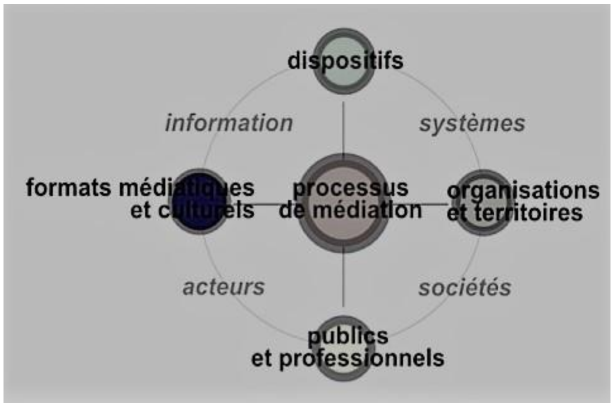

Figure 2. Diagram representing key words of Information and Communciation Sciences. Credits: Sidonie Gallot, « Les enjeux d'une cartographie des SIC pour la discipline et les unités de recherché », Revue française des sciences de l'information et de la communication [on line], 5 | 2014, DOI : https://doi.org/10.4000/rfsic.1191

III. METHODOLOGY

The arrival of new technologies has rapidly interested the tourism sector by making it enter "the era of hyper connectivity, but also of hyper socialisation"(Safaa, Oruezabala and Bidan, 2021 [11]). In this context, the tourist has everything to gain. Increasingly technophile, learning and enterprising, he seizes the technological context to gain freedom of action. The digitisation of tourism has *de facto* enabled tourists to construct their journeys autonomously, "thanks to shared content on the Internet and social networks of billions of users" (Salomone, Haddouche 2021 [12]).

This development has also opened the door to individuals wishing to provide tourism services. Beyond Airbnb, we have a number of practices such as couchsurfing, home exchange, free accommodation for services, etc.

The qualified tourist guide is also affected by this personalisation of tourism. On the one hand, the Internet allows us to have access to all types of information, to build our own tour and to have access to the information that interests us. In this way, the tourist selects only what he or she wants to know, with the risk of missing out on important or even fundamental notions for understanding the place visited. On the other hand, the development of slow tourism has encouraged the multiplication of greeters. These are local people who offer guided tours, often free of charge. So, if for a certain public, a guide can be considered useless, for another it can be seen as not authentic.

"Alternative tourism" seeks out places that are less well known, far from the traditional tourist circuits and therefore considered more authentic. In general, the choice of destination or tour is closely linked to the experience that a place or site is able to offer.

Finally, qualified tourist guides are seeing new competitors appear in the panorama of guided tours. A constant search for authenticity may lead to a preference for an experience with locals or non-professionals, rather than the knowledge of an experienced guide. Concerning the digital aspect, there are not only audio guides and digital technology in museums or historical monuments, but also and above all the Internet. The tourist, accustomed to checking every piece of information, will not lose the opportunity to question the guide's discourse, or even to cast doubt on it, more or less cordially. We can consider all this to be part of the problems of the guiding profession which are difficult to identify, or even recognise, but which are increasingly forcing professionals to rethink their approach to the client.

When we talk about new technologies associated with cultural activities, we should not think only of online booking platforms, tourism promotion websites, etc. In the age of the "intelligent tourist", making oneself known and knowing how to promote oneself is fundamental. Being present on social networks, having an interactive and always updated website, becomes then mandatory. This applies to tourist sites, heritage sites, museums, but also to professionals who provide services to tourists and, in particular, qualifies tourist guides.

We believe that qualified tourist guides should not only think about digital in the context of tour construction, but also as a tool to promote themselves (putting themselves on a show) and find new clients. Qualifies tourist guides often have a self-employed status which allows them to work with companies or tourist offices and, at the same time, have their own clientele. If we think about our "intelligent tourist", he builds his trip thanks to the information found on the internet and by consulting the reviews. Similarly, the "alternative tourist" may not choose an agency that offers tours for mass-market tourists.

These types of visitors based their choices on the idea of having a unique and personalised experience. A qualified tourist guide must therefore know how to master social networks in order to make his offer known and enlarge his audience. In a context that has been able to quickly appropriate new technologies, guide-lecturers must now integrate into their skills those related to digital uses.

The National Federation of Qualified Tourist Guides carried out a survey of guides holding a professional card in 2020, in order to "establish a general profile of the professional and social situation of qualified tourist guides in France before the Covid-19 epidemic and to have real and recent data for a year of normal activity" (Fromont, Villepelet, 2021 [13]), that is 2019. The number of active qualified tourist guides was estimated to be between 3500 and 4500, but the answers were only 1360. This survey shows that the profession is predominantly female (79%) and that about half of the respondents have been in the profession for less than 10 years (Fig. 3). On the other hand, this does not translate into relatively young professionals, as the average age was estimated at 46 years (Fig. 4). However, this study does not ask the question of the use of digital technology within a guide's activity. Similarly, a second survey carried out in 2021 [14] to show the situation of precariousness due to Covid-19, does not attempt to see whether qualifies tourist guides have used digital technology to continue their work. Indeed, it seems that the National Federation of Qualified Tourist Guides does not really consider the approach to new technologies as an essential aspect of the guiding profession, nor a skill to be acquired.

In order to confirm or refute this hypothesis, we would like to finance a survey among qualified tourist guides on the use of digital technology. We would also like to check whether the Covid crisis has been a driving force for change in this direction or whether the use of certain practices is considered to be limited to the crisis period.

More specifically, we would like to work on the invisible side of work activities from the perspective of "actor-network theory", "sociology of translation" [15] and "dark side studies" [16] by considering an "iceberg of activity" approach, in our case "tour guide's situational iceberg", in order to highlight the invisible or dark side of these situations, using a participatory research methodology currently being developed.

The national survey among practising qualified tourist guides will enable us to build a reliable and up-to-date framework of the use of digital technology and the difficulties they encounter in their work.

Then, based on interviews and participant observations, we plan to study the invisible, i.e. non-formalised, side of the guides' interactions in an activity situation, interactions with their clients, but also with the socio-technical devices, such as tablets or touch screens. We will also be interested, in the perspective notably traced by V. Carayol and A. Laborde [17], to study the resistances of the guide-lecturers to the use of new technologies by proposing a typology ranging from enthusiastic users to radical refractors.

We want to establish a grid of user types that will serve as a comparison throughout our research. At the same time, we will survey our students every year for at least 5 years. This will allow us to see how the new generations relate to the new technologies and whether there are any changes in the pyramid of user types.

At the end of these surveys, we will have the situation of qualified tourist guides in activity and that of the students, future guides; this will allow us to advance reflections in a comparative way.

Concerning the new generations, we will also deploy a participant observation approach by following four students of the class of 2021-2022 in the first years of their activity as qualified tourist guides. As with the survey, each year we will follow between two and four new guides in their profession. From this perspective, we will draw on the work of A. Mucchielli on "situational and interactionist semiotics" [7] and of M. Zacklad on the "semiotics of cooperative transactions" [18] by proposing to add this hidden dimension of the activity. In our analysis of the 'situational iceberg' of guiding activity, we will attach particular importance to trying to understand the issue of emotions which, largely invisible, contributing to the construction of the visiting situation as a whole.

To summarise, our study is developed in several stages:

1. Survey on the use of digital technology by active qualified tourist guides and drafting of a typology grid of digital users.
2. Analysis of the existence of digital resistances and their typologies.
3. Situational iceberg and participant observation of guiding activity.
4. Survey of *LP Guide-Conférencier* students on their relationship with digital technology (5 year period).
5. Question of emotions in a visiting situation.

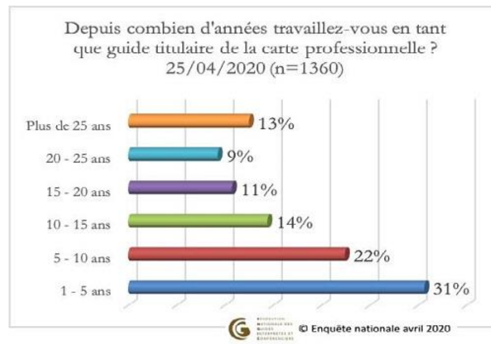

Figure 3.

Figure 3. Years of professional activity. Credits 2021 survey of the National Federation of Qualified Tourist Guides (FNGIC), carried out on the initiative of FNGIC. https://www.fngic.fr/fr/actualites/enquete-nationale-sur-metier-guide-conferencier

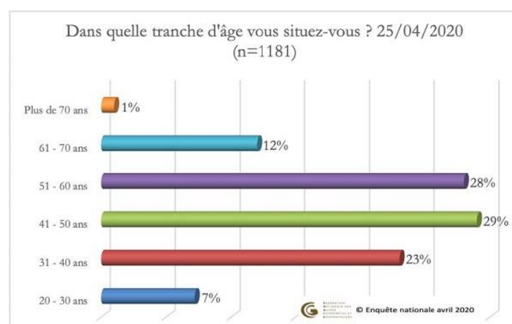

Figure 4. Age range of the respondents. Credits 2021 survey of the National Federation of Qualified Tourist Guides (FNGIC), carried out on the initiative of FNGIC. https://www.fngic.fr/fr/actualites/enquete-nationale-sur-metier-guide-conferencier

IV. OVERVIEW AND EVOLUTION OF HUMAN MEDIATION

The scope of intervention of a qualified tourist guide is very vast and covers the whole of the French cultural and natural heritage.

In France, qualified tourist guides are the only ones allowed by the law to conduct visits and lectures in museums and historical monuments (except for curators and teachers in a certain extend). We therefore chose to focus on museums and historical monuments where the digital element is increasingly important.

The functions of the museum, as we recall, are exhibition, conservation, scientific study and animation. Museums bring their collections to life and offer different approaches to reading them for different types of visitors. Animation acts as a driving force in the museum institution and can take various forms: educational activities, guided tours, lectures, concerts, workshops, events and demonstrations of all kinds [19]. Consequently, mediation approaches, whether human or digital, are based on the knowledge of public's expectations. In fact, the *modus operandi* of mediation professionals has evolved to adapt to the expectations of the public by moving from the simple discourse (from "saying") to action (to "doing"), with the rise of performative and participative interventions. As Stéphanie Airaud reminds us, "The mediator's discourse proposes to go beyond the guided tour to play on the springs of aesthetic experience. Embodied by the lecturer for an audience, this speech uses taste, sound, imagination, fiction, the illusion of image and word to invent a performative maieutic. It therefore seems possible to move from saying to doing" [20]. We consider here "*dire*" (say) as an oral transmission of a discourse on the artistic works, and "*faire*" (do) as the creation of a situation, a space for play and the advent of a form. Many guides and lecturers then invented new forms of mediation, in which the public more easily speaks up during debates, physically invests the tour framework in artistic forms (dance, poetry, meditation, etc.) or playful forms (photo rally, treasure hunt). The most important thing is to become an actor (or "spect-actor") of a new type of participative visit.

The development of digital technologies has made it possible to go further in the reflection on mediation, making it possible to offer immersive tours. Exhibitions designed in this way help visitors to immerse themselves in the artwork and to contemplate it by mobilising several senses (100% immersive).

The interactive content supports the exhibited object and offers easier and more dynamic access to information than the classic panels. It is undeniable that this type of installation facilitates the approach to culture, but when the pedagogical element is absent, the risk (for a non-educated public) is that the experience is focused entirely on emotions and not also on reflection and knowledge.

The discourse of tour guides has also evolved with the increasing access of the public to information. From the mid-2000s onwards, Wikipedia revolutionised public access to online information. As its diversity and reliability grew, tourist guides gradually lost their status as knowledge holders. They questioned the content of their discourses and sought to offer more reflection and perspective in addition to the raw information. Since the explosion of social networks in the mid-2010s, the youngest users now rarely consult traditional media and instead lock themselves into information loops. For these audiences, the discourse of the qualified tourist guide has evolved further with the return of popularisation content combined with increased vigilance on discernment since the explosion of fake news from 2016.

Qualified tourist guides therefore find themselves having to justify their discourse and their competence to a public that believes itself to be increasingly prepared and much better informed thanks to the Internet.

V. Digital, new tools for mediation in the museum and public space: the third stage in the evolution of the Tourist guide profession

Our reflection here is about the way in which the qualified tourist guide can rely on digital technology during a guided tour. We therefore exclude the use of digital technology for communication and marketing purposes [21]. The same applies to creative content of a cultural and immaterial nature which excludes *de facto* human mediation (e.education/EdTech, video games, digital publishing, digital press, 3D animation, virtual reality, augmented reality, music, audiovisual, radio, television, cinema).

We will try to show how digital can be a complementary tool for guides without trying to replace them. The Covid 19 pandemic and its many lockdowns have proved the need of human relationships and interactions in education and leisure activities. Hence the importance of closely associating and balancing the level of intervention of the digital world and the human in the mediation with the public. We can define three levels of intermediation in which digital takes a more or less important place.

In 100% immersive (fig. 5), the public wanders through spaces with high level of scenography which use interactive digital tools in different contexts and for different purposes and where guides don't have a lot of opportunities for their intervention. The first type offers immersive exhibitions of digital creations on artistic themes, such as the *Atelier des Lumières* [22] in Paris. The second type offers a tour combining immersive content and varied interactive digital content with the aim of facilitating the understanding of a subject. This is the case of the *Château d'Auvers sur Oise* [23] focusing on 19th century art. In a constrained tour, visitors wander from room to room interacting with various contents and operating modes. It should be noted that this type of mediation can be very useful for people with motor or visual and hearing disabilities...

Finally, the third type makes use of new technologies as an innovative positioning in terms of product, which enables it to stand out in the cultural offer of a destination. This is the case of the *Hôtel de la Marine* in Paris [24], which opened in 2021 and offers an immersive tour within highly planned environment and constrained pathway using various devices to enhance the visitor experience.

Some cultural places offer interactive or immersive contents while allowing the guide to intervene at key moments in the visit. This is the case at the *Cité des Sciences et de l'Industrie* in Paris (Fig. 6) [25], where permanent and temporary exhibitions are accessible on their own or with a guide. In this case, it is necessary for the guide or scientific mediator to be aligned with the imposed scenography by becoming familiar with contents and operating modes of the digital tools in order to integrate them into his tour and its discourse. Consequently, he must be a specialist in the subjects covered in order to be able to deliver the necessary information, answer to certain questions from the public and achieve an optimal customer experience.

The third level of intermediation takes place in environments with lesser scenography and leaves much more opportunities to the guide to integrate digital technology into his visit. This is the case of the *Sainte Chapelle* in Paris [26], which has a freely accessible interactive digital table offering 3D reconstructions of the place and its surroundings during the history. It is large enough for a dozen of people to gather around and can easily be used during the visit to support the guide's presentation. Augmented reality offers a significant cognitive support in understanding and reinforcing the content delivered by the guide. Here again, the guide must be familiar with the contents and functionalities of the tool in order to be able to integrate them perfectly into his tour scenario. Similarly, the *Conciergerie* in Paris offers its visitors *histopads* [27] (Fig. 7), which provide 3D reconstructions of the site, also in augmented reality, accompanied by written information. These can easily be integrated into a tour in which the guide will find in this tool an ally enabling him to evoke the atmosphere of a place that is now not so furnished and decorated.

In these places, the digital visit materials are very often designed and produced without taking the guide into account, not involving him into the creative, design and planning process. Even if, for some museums, guided tours represent a less important part in terms of attendance than the self-guided tours for which these tools are designed, we can only encourage a dialogue in which museums consults its guides or mediators for the selection of digital tools and the drawing up of specifications for the contents and operating methods. The objective is to meet the needs of the public in a guided tour situation and to offer the guide a better appropriation and a more relevant integration of the tool in his visit according to contents and operating methods that are adapted to his visit.

The emergence of digital technology must be integrated into a perspective of human interaction to encourage the creation of new services. The 100% immersive, in particular, obliges the actors of cultural and scientific mediation to a new approach of service definition and guides more precisely to an in-depth reflection on how to give a new added value to their profession.

Despite the interest and progress brought by the variety of digital tools, we do not think that 100% digital is the most relevant approach in terms of services, public mediation, and product. In the same way that we have integrated the hybrid into professional, medical or relational perspectives, human mediation must remain at the centre of these approaches, and this is why we propose to integrate the expertise of qualified tourist guides into the design of digital tools. In the graph below (Fig. 8) we show the difference between opportunities of mediation and easiness of mediation according to the degree of digitization:

- The opportunities (dotted line) exist as soon as there is at least one digital tool, and they decrease with the intervention of immersive content and scenography

- The easiness for the guide is optimal when he has more variety of choice of digital supports as he is not forced to use the one and only available which may not be relevant for his visit.

Easiness starts to drop as soon as the content is immersive (histopad for example with its predetermined immersive scenario), and collapses in an immersive scenographic environment.

Note that the difficulty of mediation also depends on the complexity of the scenario of the digital tool, which the guide should manage and be comfortable with to integrate it in his visit.

Figure 5. Atelier des lumières, Paris. Credits: photo taken on the Atelier des lumières' website https://www.atelier-lumieres.com/fr

Figure 6. View of the permanent exposition of the Cité des Sciences et de l'Industrie Museum in Paris. Credits: photo taken on the museum's website https://www.onetwotrips.com/cite-des-sciences-la-villette/

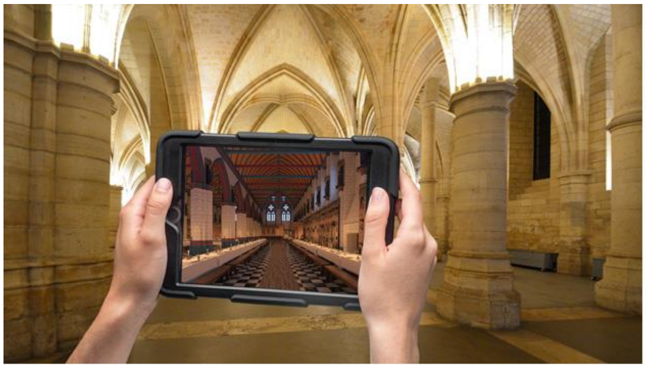

Figure 7. Histopad of the Conciergerie Palace in Paris. Credits Musée de la Conciergerie http://www.paris-conciergerie.fr/Actualites/Decouvrez-la-Conciergerie-avec-l-Histopad

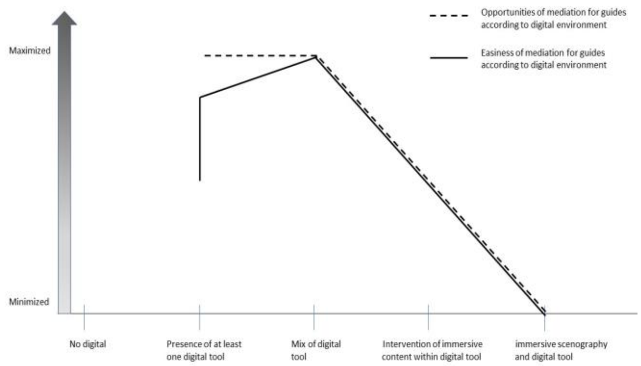

Figure 8. Difference between opportunities of mediation and easiness of mediation according to the degree of digitization.

VI. FUTURE TOURIST GUIDES-FACING ICT

The digital media present in the museums are designed to accompany an individual visit and provide in-depth information that the visitor must be able to use independently. The mediation offered by the museum is not necessarily intended to use these media either. At the same time, within the framework of our bachelor's degree, we have noticed that until now future qualified tourist guides have not shown a significant interest in new technologies, but this is changing very quickly with the renewal of generations. The profession of guide is still largely perceived in a purely interactional reading without measuring the interest and need of the integration of new technological tools. The relationship with digital technology is still limited to treasure hunts or to a complementary communicative role, which may raise questions about the employability of future tourist guides, particularly regarding the acquisition of new segments of the public who are increasingly equipped with tools and applications that can be used to carry out a tour otherwise perceived as basic. Furthermore, appropriating new technologies would allow guides to position themselves in the market of 3D reconstructions and 100% immersive, thus ensuring the continuity of the profession. A qualified tourist guide, in addition to his cultural background and knowledge of the various audiences, could show and additional knowhow in technical skills that would be useful for the design of digital products offering progressive interpretating frameworks required by the different stages of a well-prepared visit.

As for qualified tourist guides already in activity, we have the impression that the new generations are still not at ease with the digital world and that they continue to consider the profession with a very traditional approach. We are therefore going to carry out surveys among our students, in order to verify our hypothesis and possibly understand what types of skills should be integrated into their scholarship. From the perspective defined by Laborde and Soubiale [17], we will analyse the resistance to the appropriation of digital technology for the guiding profession. We believe that, while the development of digital technology presents mortal dangers for the traditional approach to guiding, it also opens up great opportunities for those who will be able to adapt to the irreversible digital transformation taking place. We will start with the students of this academic year 2022-2023, and will carry out one survey per year for a minimum of five years. This will allow us to see the evolution of the new generations.

For the moment, to fill this gap in the integration of qualified tourist guides in the design of public mediation projects, Gustave Eiffel University encourages a close collaboration between touristic sites and guides to involve them in the creation of digital tours. For example, in 2018, a student of our professional degree developed a tour of the Gallo-Roman site of *Le Fâ (Barzan, Charente-Maritime)* using geocaching [28]. The visitors were offered to walk through the site on their own with the aim of finding caches according to an itinerary planned by the management and the guide. The scenario of visit foresaw that the guide would be near strategic caches to offer additional information on the history, archaeology, the site, etc., and to answer to visitors' questions. This twofold interpretative approach responds to the issue of the types of discourse explained in part 2: to propose a framework of information completed by exchanges in the form of questions.

Gustave Eiffel University and IFIS [29] are currently setting up exchanges between student guides and students of the Tourism and New Technologies professional degree in order to allow exchanges on each other's practices, and also to help our future guides to integrate an ICT dimension into their end-of-study projects in order to better prepare themselves to accompany publics who make increasing use of tools, applications and digital practices.

Some students from the *Guide-Conférencier* degree 2021-2022 carried out a project for a guided tour of the Louvre Museum in Paris in the form of a treasure hunt using digital tablets. They prepared specifications for the developers to work together on the content, ergonomics and functionalities of the application in order to make this treasure hunt fun, by integrating immersive and participative solutions. The didactic content has been provided by the qualified tourist guides who will be positioned at strategic points to offer additional information and answer questions.

In the past class (2021-22), we also had students who brought up reflections on the use of digital technology by qualified tourist guides. Each of them developed the subject from a different angle:

- The use of social networks to sell their tours. This dissertation focuses on the benefits that the use of social networks can bring to the profession of qualified tourist guides; in particular, how to use social networks for free in order to start and/or expand one's activity. The study considers several platforms, with a particular focus on Facebook and Instagram.

- Virtual tours to reach remote audiences. During the Covid-19 pandemic, cultural sites and museums developed more virtual tours and some qualified tourist guides conducted virtual tours in order to build customer loyalty. However, this type of activity does not allow for interaction between the tourist guide and the public to the extent that, in most cases, these practices are considered to be limited to the crisis period. One of our students wondered how to take advantage of these good practices in times of crisis. It turns out that there is a potential market that is very little exploited by guide-lecturers: that of remote audiences. People with disabilities, the very old or sick who cannot travel. Or secondary school classes that have to limit their outings for budgetary reasons. With the help of digital media, the qualified tourist guide can go to the client's home and take a virtual tour. The human side, as well as the interactions, are preserved because the qualified tourist guide is physically with the client. In addition, new technologies make it possible to create immersive scenarios and to offer fun activities, such as treasure hunts or quizzes.

- The contribution of a tourist guide in the creation of serious games for museums. This is a reflection on the usefulness of serious games in the learning activity and for the appropriation of contents through the setting in situation, in particular for young people. The student asks himself how to build a guided tour around game and what it may be the contribution of a qualified tourist guide to this type of activity often carried out by mediators.

- The activity of tourist guides in the service of the development of a territory. Based on a case study, the town of Cap d'Agde, the dissertation proposes a strategy of action to make seaside tourists interested in the cultural heritage of the territory. More generally, this study allows us to reflect on an important role of a qualified tourist guide, that of being an “ambassador” for a territory. This is particularly true when we think of local qualified tourist guides who work outside the major tourist destinations. Through his knowledge of the territory, of local life, and through the passion that he can transmit, a qualified tourist guide contributes to the promotion of a territory through his guided tours.

From this year onwards, we are going to follow these students, who are now qualified tourist guides, in their activity to see how they develop their professional projects. We are also going to set up a working group that can integrate researchers, teachers and young professionals to reflect on the scope of digital technology in this profession and propose new practices.

VII. Conclusion – Perspectives

We have traced here, although in a synthetic way, the evolution that the profession of tourist guides has undergone over the years and with the arrival of digital technology.

We have shown how much the new uses of digital technology condition the evolution of this profession of mediation facing of audiences that are increasingly using digital technology. To ensure the sustainability of their profession, guides must know how to adapt to this new context and give added value to their interventions. All these developments in the digital transformation take on an additional significance in times of the Covid pandemic, which reminds us how essential and necessary human interaction is. This new perspective has moreover imposed a major reinvention of the profession of qualified tourist guides, notably towards new remote services now integrated into their service offer. It is therefore not a question of putting ourselves in opposition to digital media, but rather of learning to use them so that they become our allies.

It is now clear that qualified tourist guides can no longer deny that new technologies have changed their working environment, yet the approach to digital is still limited and it is not seen as an opportunity either.

Our study then becomes necessary to outline the current context, although it would be the first study in this sense, in order to understand where the resistance of working qualified tourist guides to digital technology lies, despite the fact that it is essential to integrate it into the evolution of their profession and its use has become unavoidable.

We also wish to conduct research among the students of our professional bachelors’ degree to better understand their approach to digital technology and to propose an educational pathway that meets the requirements of the market. Secondly, we would like to develop collaborations between guides and computer scientists to make the tour app even more effective [30], [31].

Research of this kind will help to identify the hidden difficulties of the qualified tourist guide's profession but also to understand the future of this job.

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Component Framework Implementation and Realisation for Development and Deployment of a Coherent Multi-disciplinary Conceptual Knowledge-based Holocene-prehistoric Inventory of Volcanological Features Groups and Faceting

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Abstract—**This paper presents extended insight in results and current status of the procedural component framework implementation and realisation for creation of a coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of worldwide volcanological features groups, especially enabled by conceptual knowledge facets. The goal is the creation of a sustainable framework of components, which can be employed for multi-disciplinary integration of knowledge contexts, especially from prehistory and archaeology. The component framework has to enable further coherent conceptual knowledge contextualisation and georeferenced symbolic representation. This paper provides the results on experiences of sustainable component integration and practical procedural implementations and realisations. Future research will address the creation of a component framework for a Holocene-prehistoric inventory of worldwide volcanological features, which enables coherent multi-disciplinary conceptual knowledge integration and contextualisation with prehistorical and archaeological knowledge resources.**

***Keywords*–Prehistory, Prehistoric Archaeology, and Holocene; Knowledge-based Contextualisation and Component Integration; Coherent Multi-disciplinary Conceptual Knowledge Faceting and Integration; CRI Framework; CKRI.**

I. Introduction

This paper is an extended and updated presentation of the research based on the publication and presentation at the INFOCOMP 2022 conference in Porto, Portugal [1]. Due to a number of requests for the created inventory, this extended paper concentrates on the practical inventory and procedural knowledge complements, showing a wider range of result groups based on practical facets used for on-demand contextualisation and symbolic representation.

The corresponding coherent complementary results and details on faceting from the research groups on multi-disciplinary conceptual knowledge [2] are further developed and have to be given in a separate publication [3]. That research concentrates on the conceptual knowledge reference implementation and realisation, the fundaments for creation of a multi-disciplinary coherent conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups along with the overall frame [4] and importance of information science methods and structures [5].

The overall multi-disciplinary contextualisation and faceting enables to integrate the state of the art scientific research results from respective disciplines on equal footing of knowledge and scientific level.

It can integrate a wide range of methodological approaches used in disciplines, e.g., conceptual knowledge based methods, chorology based methods, e.g., place described by conceptual knowledge and other factual knowledge like position, height, depth, chronology based methods, visualisation based methods, handling of multi-disciplinary contexts.

Coherent conceptual knowledge resources are results of often complex and long-term multi-disciplinary creation processes. Coherent conceptual knowledge resources may have to achieve an advanced level of implementation before procedural components can be created for sustainably employing these resources. The conceptual knowledge implementation for this inventory is in focus of multi-disciplinary research groups and matter to be reported in separate publications. Motivation is the creation of a sustainable and practical component framework based on coherent multi-disciplinary conceptual knowledge.

This paper presents the results of the procedural component framework implementation and realisation for creation of a coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of worldwide volcanological features groups, which are employing respective coherent knowledge resources. The goal of this research is the creation of a sustainable framework of components, which can be employed for multi-disciplinary integration of knowledge contexts, especially from prehistory and archaeology, too. The component framework further has to enable a coherent conceptual knowledge contextualisation and georeferenced symbolic representation.

The rest of this paper is organised as follows. Section II presents the major reference implementations. Section III presents the methodological implementation and realisation, workflow procedure, respective component reference implementation and integration and coherent conceptual knowledge implementation for the new inventory. Section IV discusses the procedural potential regarding integration of components, parallelisation, and implementation features. Section V summarises lessons learned, conclusions, and future work.

II. Major reference implementations

The coherent knowledge resources and the practical realisation are fully based on the Component Reference Implementations (CRI) framework [6], which is employing the main implementations of the prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI) [7]. CRI provides the required component groups and components for the implementation and realisation of all the procedural modules. CKRI provides the knowledge framework, including multi-disciplinary contexts of natural sciences and humanities [8]. Both provide sustainable fundaments for highest levels of reproducibility and standardisation and allow continuous and consistent further development of discipline-centric and multi-discipline development of knowledge resources. Both reference implementations and all components are in continuous further development by the respective disciplines themselves.

The approach conforms with information science fundaments and universal knowledge and enables an integration of the required components from methodologies to realisations for knowledge representations of realia and abstract contexts [9], namely the Conceptual Knowledge Pattern Matching (CKPM) methodology, considering that many facets of knowledge, including prehistory, need to be continuously acquired and reviewed [10].

III. Methodological implementation and realisation

Implementation and realisation are based on the CKRI [7]. Components outside the core scope of this geoscientific, prehistoric, and archaeological research are employed and can be extended via the CRI frame [6].

The employed CKRI corresponds with development stage editions, prehistory-protohistory and archaeology E.0.4.8, natural sciences E.0.4.0). The CKRI implementations provide the fundament for the coherent multi-disciplinary knowledge based integration and the realisations of the methodological component integration. Integration components, reflecting standards and sustainable modules are based on the major groups of the Component Reference Implementations (CRI) frame [6]. The employed CRI framework corresponds with development stage edition E.0.3.9.

The conceptual knowledge implementation is the major practical knowledge-based result, a tool, which can be employed for enabling multi-disciplinary coherent knowledge-based contextualisation and solutions. The component framework provides integrated tools for realising solutions based on such multi-disciplinary coherent knowledge contextualisation.

The results and presentation are designed for multi-disciplinary audience willing to expand their methodological and practical facilities towards creating sustainable multi-disciplinary solutions deploying components, which can enable advanced coherent conceptual knowledge integration for knowledge-based projects. As employed for demonstration, the examples do not require expertise in volcanology but understanding and practical deployment may require the will to learn new methods, even naturally complex contexts, and advanced components, enabling fundaments and facilities.

The following implementation and realisation start with a description of a workflow procedure for creation of a coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of worldwide volcanological features groups, followed by the component implementation and realisation based on the general coherent multi-disciplinary conceptual knowledge implementation.

A. *Methodological workflow procedure*

A workflow procedure for the creation closely integrates the component framework and the coherent knowledge implementation of the Knowledge Resources (KR):

- (KR/components selection, continuous development.)
- Component implementation and realisation.
  - Scientific parametrisation of components (including algorithms, in each discipline).
  - Workflow decision making.
  - Country identification algorithm.
  - Country representation algorithm.
  - Area of Interest (AoI) representation algorithm.
  - Symbolic representation of country
  - Symbolic representation of AoI.
  - Knowledge and discipline depending algorithm creation.
  - Knowledge Resources processing.
  - Chorological assignment and processing, e.g., spatial calculations, e.g., countries and areas.
  - Chronological assignment and processing, e.g., time related calculations, e.g., geological and prehistoric.
- Coherent conceptual knowledge implementation.
  - Coherent conceptual knowledge references, main tables.
  - Coherent conceptual knowledge references, auxiliary tables.
- Symbolic representation, generation.
  - Context area views.
  - Symbolic representation of features groups, integrated visualisation.
  - (Further symbolic representation of narratives.)
  - (Multitude of further contextualisation and narratives.)
  - . . .

After understanding the selected task-related algorithms and the fundamentals of knowledge complements many different realisations can be done straightforward, deploying the CKRI and CRI framework components.

The symbolic representation of features groups and the integrated visualisation will provide manifold ways of contextualisation. We can only demonstrate a single group of examples here.

Nevertheless, the realisation of the implemented workflow procedure may depend on the capacities the participating disciplines want to invest in their education, scientific research and contextualisation. It should not be uncommon with today's scientific research to invest increasing resources, 25 to over 50 percent of overall project resources, of each participating discipline into multi-disciplinary knowledge integration and contextualisation.

The CKRI and CRI framework can create coherent multi-disciplinary conceptual knowledge references effectively and efficiently and focus on core tasks within available capacities of time and other resources available for a workflow procedure.

B. *Component implementation and realisation*

The following passages give a compact overview of the major component framework integrated with this research. All the components and references are given, which were employed for the implementation and realisation and which are in a continuous further development process towards even closer integration and standards. More detailed, comprehensive discussion and examples regarding fundaments are available with the references on knowledge representations, methodology, contextualisation, and conceptual knowledge.

a) Conceptual knowledge frameworks: The created and further developed reference implementations of conceptual knowledge frameworks (this research major references in Tables I and II) are used with the implementation and realisation

KR [11]. CKRI can be created by any disciplines and for multi-disciplinary scenarios and coherently integrated, e.g., in contextualisation for prehistorical and archaeological narratives.

b) Conceptual knowledge base: Conceptual knowledge base is The *Universal Decimal Classification (UDC)* [12], a general plan for knowledge classification, providing an analytico-synthetic and *faceted* classification, designed for subject description and indexing of content of information resources *irrespective of the carrier, form, format, and language*. UDC-based references for demonstration are taken from the multi-lingual UDC summary [12] released by the UDC Consortium, Creative Commons license [13].

c) Integration of scientific reference frameworks: Relevant scientific practices, frameworks, and standards from disciplines and contexts are integrated with the Knowledge Resources, e.g., here details regarding volcanological features, chronologies, spatial information, and Volcanic Explosivity Index (VEI) [14], [15].

d) Formalisation: All integration components, for all disciplines, require an *explicit and continuous formalisation* [16] *process*. The formalisation includes computation model support, e.g., *parallelisation standards, OpenMP* [17], [18], Reg Exp patterns, e.g., *Perl Compatible Regular Expressions (PCRE)* [19], and common standard methods, algorithms, and frameworks.

e) Methodologies and workflows integration: Methodologies for creating and utilising methods include model processing, remote sensing, spatial mapping, high information densities, and visualisation. Respective contextualisation of (prehistoric) scenarios should each be done under specific (prehistoric) conditions, especially supported by state-of-the-art methods, e.g., spatial operations, triangulation, gradient computation, and projection. The symbolic representation of the contextualisation can be done with a wide range of methods, algorithms, and available components, e.g., via LX Professional Scientific Content-Context-Suite (LX PSCC Suite) [20] deploying the Generic Mapping Tools (GMT) and integrated modules [21] for visualisation.

f) Prehistory Knowledge Resources: Prehistoric objects and contexts are taken from *The Prehistory and Archaeology Knowledge Archive (PAKA)*, in continuous development for more than three decades [22] and is released by DIMF for the previous working edition [23] and this work [24]. The KR support seamless coherent multi-disciplinary conceptual knowledge integration for workflow procedures.

g) Natural Sciences Knowledge Resources: Several coherent systems of major natural sciences' context object groups from *KR realisations* have been implemented, especially Knowledge Resources focussing on volcanological features [14] deployed with in depth contextualisation [15] and with a wide range of contexts [11], [12], [25]. The KR support seamless coherent multi-disciplinary conceptual knowledge integration for workflow procedures.

h) Inherent representation groups: The contextualisation for the inventory can employ state-of-the-art results from many disciplines, e.g., context from the natural sciences resources, integrating their inherent representation and common utilisation, e.g., *points*, *polygons*, *lines*, *Digital Elevation Model (DEM), Digital Terrain Model (DTM), and Digital Surface Model (DSM) representations* sources, e.g., from *satellites*, Unmanned Aerial Vehicles (UAV), *z-value representations*, *distance representations*, *area representations*, *raster*, *vector*, *binary*, and *non-binary data*. Employed resources are High Resolution (HR) (Space) Shuttle Radar Topography Mission (SRTM) [26], [27], HR Digital Chart of the World (DCW) [28], and Global Self-consistent Hierarchical High-resolution Geography (GSHHG) [29]. SRTM was produced under the National Aeronautics and Space Administration (NASA) Making Earth System Data Records for Use in Research Environments (MEaSUREs) program. The Land Processed Distributed Active Archive Center (LPDAAC), USA [30], operates as a partnership between the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), USA, and is a component of NASA's Earth Observing System Data and Information System (EOSDIS). Resources are released by NASA and JPL Jet Propulsion Laboratory (JPL), USA, [31], [32]. SRTM15 Plus [26], [27] is continuously updated and improved.

i) Scientific context parametrisation: Scientific *context parametrisation of prehistoric targets* can use the overall insight from all disciplines, e.g., parametrising algorithms and creating palaeolandscapes. Parametrisation is supported for all contexts and can consider views of participated disciplines. For the new inventory, parametrisation ranges from contexts, methods, representation of heights, illumination, symbol design, symbolic consistency to data locality and parallelisation.

j) Structures and symbolic representation: Structure is an organisation of interrelated entities in a material or non-material object or system [25]. Structure is essential in logic as it carries unique information. Structure means features and facilities. There are merely higher and lower facility levels of how structures can be addressed, which result from structure levels. Structure can, for example, be addressed by logic, names, references, address labels, pointers, fuzzy methods, phonetic methods. The deployment of long-term universal structure and data standards is essential. Relevant examples of sustainable implementations are *NetCDF* [33] based standards, including advanced features, hybrid structure integration, and parallel computing support (*PnetCDF*) and generic multi-dimensional table data, standard xyz files, universal source and text based structure and code representations.

C. Resulting coherent conceptual knowledge implementation

The CKRI implementations provide the fundament for the coherent multi-disciplinary knowledge based integration and the realisations of the methodological component integration.

Universally consistent conceptual knowledge of CKRI references, based on UDC code references, for demonstration, spanning the main tables [34] shown in Table I. Table II shows an excerpt of universally consistent conceptual knowledge of CKRI references, based on UDC code references, spanning auxiliary tables [35].

The tables contain major UDC code references required for the implementation and realisation of the methodological workflow procedure, especially for place (countries and AoI), time (Holocene), and disciplines (volcanology and prehistory).

D. Resulting symbolic representation of features groups facets

The procedural component framework implementation and realisation enable the creation of numerous contextualisations and symbolic representations for the coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups.

TABLE I. CKRI IMPLEMENTATION OF COHERENT CONCEPTUAL KNOWLEDGE CONTEXTUALISATION; MAIN TABLES (EXCERPT).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information. Documentation. Librarianship. Institutions. Publications
UDC:1	Philosophy. Psychology
UDC:2	Religion. Theology
UDC:3	Social Sciences
UDC:5	Mathematics. Natural Sciences
UDC:52	Astronomy. Astrophysics. Space research. Geodesy
UDC:53	Physics
UDC:539	Physical nature of matter
UDC:54	Chemistry. Crystallography. Mineralogy
UDC:55	Earth Sciences. Geological sciences
UDC:550.3	Geophysics
UDC:551	General geology. Meteorology. Climatology. Historical geology. Stratigraphy. Palaeogeography
UDC:551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena. Eruptions
UDC:551.2. . .	Fumaroles. Solfataras. Geysers. Hot springs. Mofettes. Carbon dioxide vents. Soffioni
UDC:551.44	Speleology. Caves. Fissures. Underground waters
UDC:551.46	Physical oceanography. Submarine topography. Ocean floor
UDC:551.7	Historical geology. Stratigraphy
UDC:551.8	Palaeogeography
UDC:56	Palaeontology
UDC:6	Applied Sciences. Medicine, Technology
UDC:7	The Arts. Entertainment. Sport
UDC:8	Linguistics. Literature
UDC:9	Geography. Biography. History
UDC:902	Archaeology
UDC:903	Prehistory. Prehistoric remains, artefacts, antiquities
UDC:904	Cultural remains of historical times

TABLE II. CKRI IMPLEMENTATION OF COHERENT CONCEPTUAL KNOWLEDGE CONTEXTUALISATION; AUXILIARY TABLES (EXCERPT).

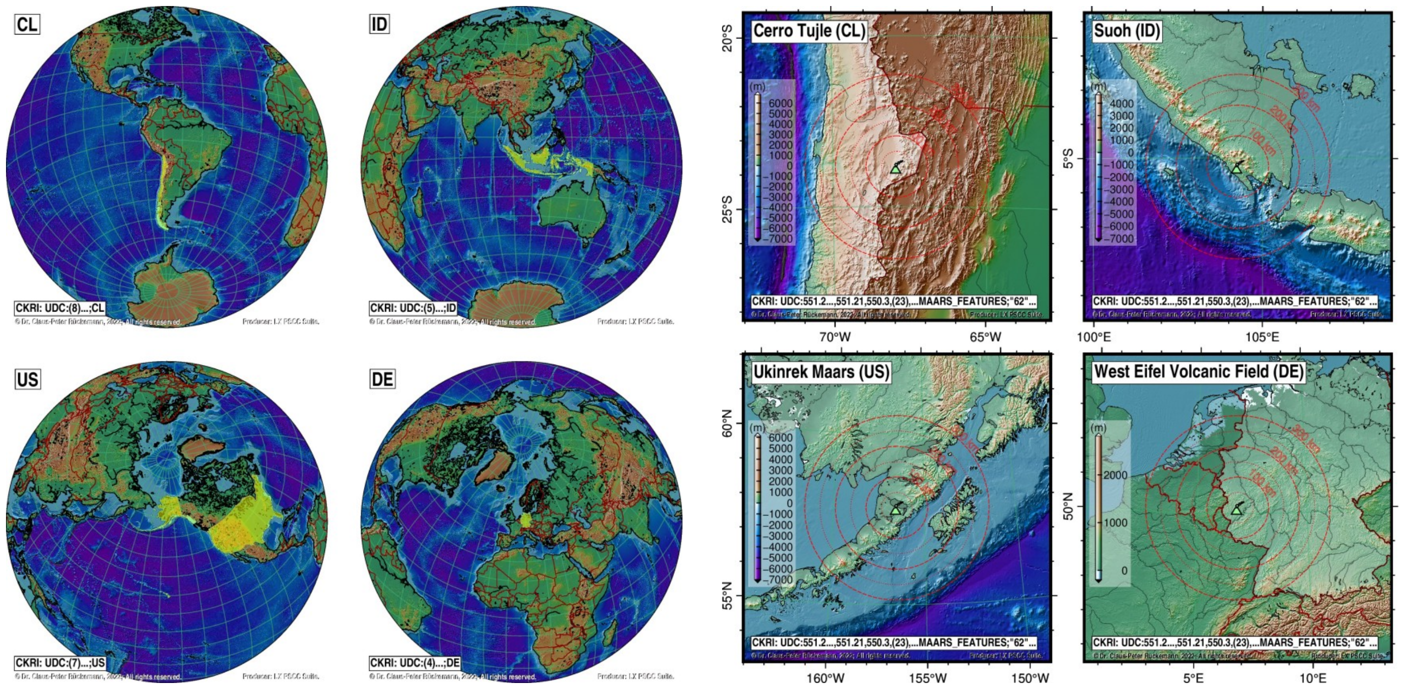
Code / Sign Ref.	*Verbal Description (EN)*
UDC (1/9)	Common auxiliaries of place
UDC:(23)	Above sea level. Surface relief. Above ground generally. Mountains
UDC:(3/9)	Individual places of the ancient and modern world
UDC:(3)	Places of the ancient and mediaeval world
UDC:(32)	Ancient Egypt
UDC:(35)	Medo-Persia
UDC:(36)	Regions of the so-called barbarians
UDC:(37)	Italia. Ancient Rome and Italy
UDC:(38)	Ancient Greece
UDC:(399)	Other regions. Ancient geographical divisions other than those of classical antiquity
UDC:(4/9)	Countries and places of the modern world
UDC:(4)	Europe
UDC:(5)	Asia
UDC:(6)	Africa
UDC:(7/8)	America, North and South. The Americas
UDC:(7)	North and Central America
UDC:(8)	South America
UDC:(9)	States and regions of the South Pacific and Australia. Arctic. Antarctic
UDC:"..."	Common auxiliaries of time.
UDC:"6"	Geological, archaeological and cultural time divisions
UDC:"62"	Cenozoic (Cainozoic). Neozoic (70 MYBP - present)
UDC:"63"	Archaeological, prehistoric, protohistoric periods and ages

For this research, we choose the resulting symbolic representation of a volcanological features group, maars, based on the coherent conceptual knowledge integration. Symbolic representation of contexts includes position based global projection of bathymetry / topography, automated country identification, multi-disciplinary context selection and reduction, chorological symbolic representation, geospherical projection considering national administrative boundaries. The symbolic representation of the global country identification exactly corresponds chorologically with that of the respective AoI context. Therefore all central positions of the representation are targeted to be precisely those of the volcanological object entities here.

The sequence of procedural steps enables contextualisation for flexible larger and smaller context scales, e.g., generated symbolic representation (Figure 1) of country identification contexts (Figure 1(a)) and generated symbolic representation of AoI contexts for respective object entities (Figure 1(b)). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas, based on the coherent conceptual knowledge.

The requested volcanological features groups facets created from the result matrix comprise the following objects with the status of this publication. The names are given along with the country code. The results of requested volcanological features groups facets and country identification contexts are given, along with the generated symbolic representation of AoI contexts for respective object entities. Context example references target Prehistoric Volcanic Activity (PVA) [3] for all volcanological features groups here, for the Holocene-prehistoric inventory. Due to the multi-disciplinary complexity and amount of contributions, complementary results and details from the research groups on multi-disciplinary conceptual knowledge have to be given in a separate publication [3].

- *Maars features:* Cerro Tujle (CL), Suoh (ID), Ukinrek Maars (US), West Eifel Volcanic Field (DE); (Figure 1: Country identification contexts, Figure 1(a); generated symbolic representation of AoI contexts for respective object entities, Figure 1(b)).
- *Strato volcano:* Agua de Pau (PT), Alngey (RU), Azuma (JP), Hekla (IS); (Figure 2: Country identification contexts, Figure 2(a); generated symbolic representation of AoI contexts for respective object entities, Figure 2(b)).
- *Shield volcano:* Volcán Darwin (EC), Kilauea (US), Santorini (GR), Waesche (AQ); (Figure 3: Country identification contexts, Figure 3(a); generated symbolic representation of AoI contexts for respective object entities, Figure 3(b)).
- *Explosion crater:* Bunyaruguru Field (UG), Dallol (ET), Koranga (PG), San Luis Gonzaga, Isla (MX); (Figure 4: Country identification contexts, Figure 4(a); generated symbolic representation of AoI contexts for respective object entities, Figure 4(b)).
- *Volcanic field:* Four Craters Lava Field (US), Gallego (SB), Volcán de San Antonio (ES), Volcán de Flores (GT); (Figure 5: Country identification contexts, Figure 5(a); generated symbolic representation of AoI contexts for respective object entities, Figure 5(b)).
- *Subglacial volcano:* Hoodoo Mountain (CA), Katla (IS), Loki-Fögrufjöll (IS), Volcan Viedma (AR); (Figure 6: Country identification contexts, Figure 6(a); generated symbolic representation of AoI contexts for respective



(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 1. Resulting symbolic representation of a volcanological features group facet (maars) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

object entities, Figure 6(b)).

- *Submarine volcano:* Campi Flegrei Mar Sicilia (IT), Curacoa (TO), Shin-Iwo-Jima (JP), Vestmannaeyjar (IS); (Figure 7: Country identification contexts, Figure 7(a); generated symbolic representation of AoI contexts for respective object entities, Figure 7(b)).
- *Cones:* Bus-Obo (MN), Kabargin Oth Group (GE), Tore (PG), Tutuila (AS); (Figure 8: Country identification contexts, Figure 8(a); generated symbolic representation of AoI contexts for respective object entities, Figure 8(b)).
- *Complex volcano:* Marapi (ID), Soretimeat (VU), Unzen (JP), Vesuvius (IT). (Figure 9: Country identification contexts, Figure 9(a); generated symbolic representation of AoI contexts for respective object entities, Figure 9(b)).

In addition to these inventory groups facets, the high-resolution resources from different disciplines like prehistorical and classical archaeology, natural sciences, and humanities, all contributing to the component implementations and realisations enable to create consistent and coherent contextualisation for large scale scenarios up to site survey scales, e.g., for detailed object level diagrams and / or for a few kilometres of spatial extend.

IV. Discussion of procedural potential

Logic is a general limit to many overblown claims, from universal parallelisation to ‘Artificial Instruments’.

Therefore, parallelisation can only deliver feasible approaches for simple, formalised cases of contextualisation and small parts of much more complex contexts of knowledge. The goals and complexity of conceptual knowledge-centric tasks and procedural tasks require the insight of eminently suitable structures and resources.

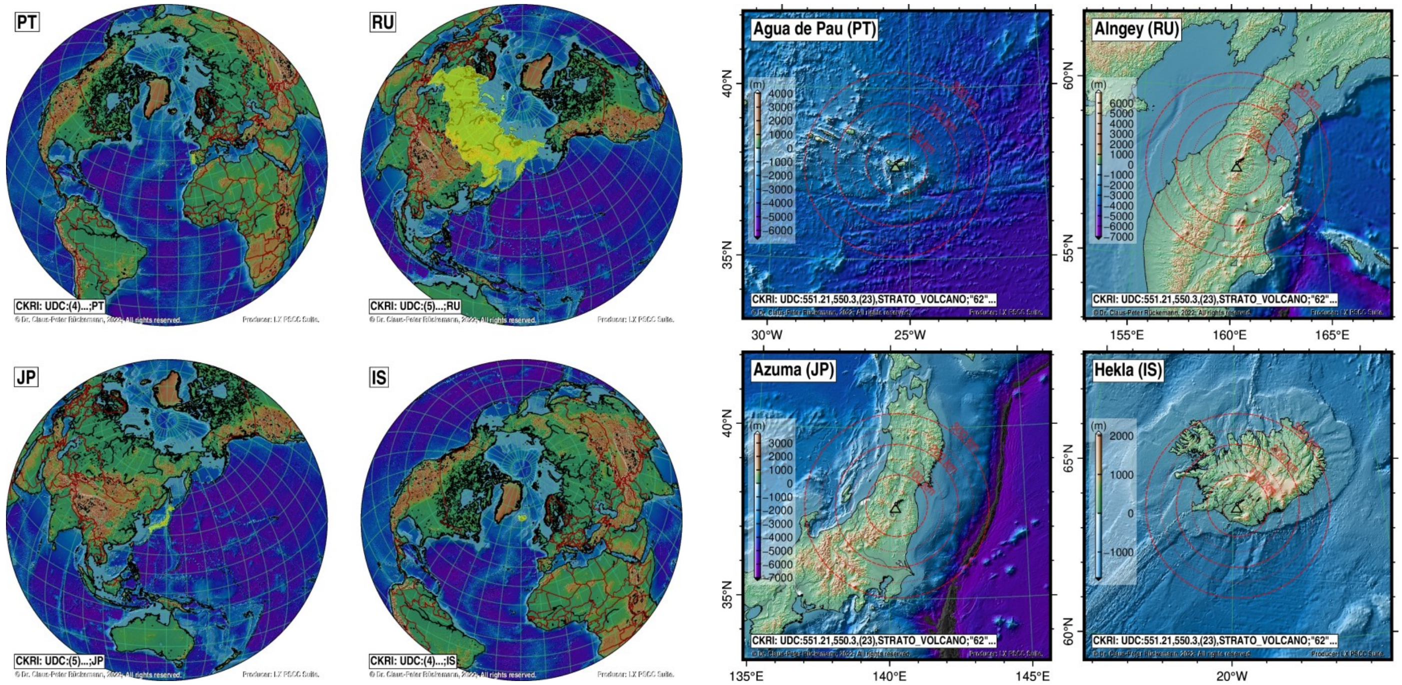
The resources, which provide highest potential for the realisation based on the inventory model are huge, based on quantity and resulting from quality of the contextualisation resources. Models are even continuously growing when considering ongoing state-of-the-art research. In consequence, these scenarios require a high level of scalability. A realistic conceptual-procedural environment for the coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups includes:

- Different object groups, objects and views, e.g., for over 500 volcanological object entities and features.
- Multi-dimensional views, e.g., focus dependent views per objects, e.g., via OpenMP [17] / specifications [18].
- Embarrassingly parallel procedures (e.g., knowledge dimensional computation), e.g., via OpenMP [17] and specifications [18].
- Job parallel procedures (e.g., knowledge objects and resources localities).

Parallelisation does not solve knowledge related challenges of discipline inherent complexity but it can help to cope with implementation challenges of procedural and computational matters.

Table III shows the inherent representation groups used by the disciplines for the formalised representation of knowledge integrated for the implementation and realisation (serial, parallel, not applicable, n.a.).

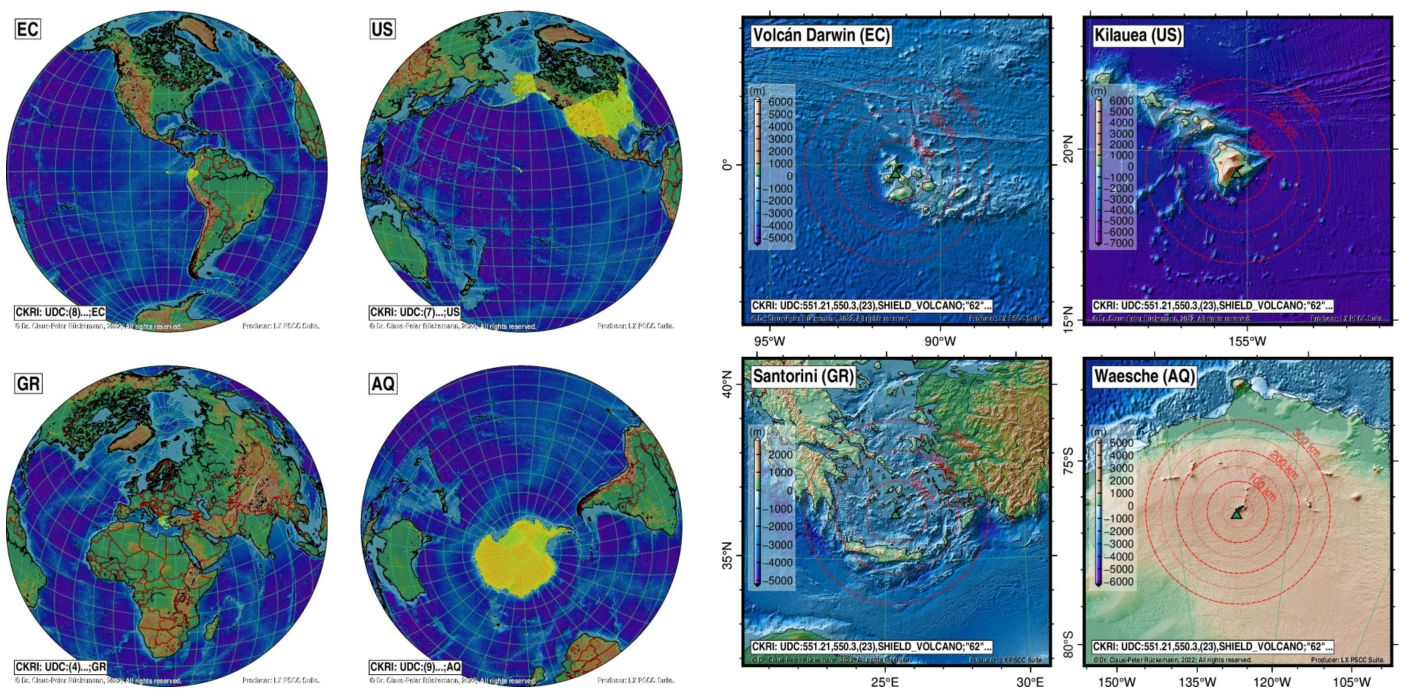
The respective locality-license and parallelisation aspects refer to the realisation resources, primarily depending on the respective knowledge and organisation. Therefore, precondition



(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 2. Resulting symbolic representation of a volcanological features group facet (stratovolcano) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.



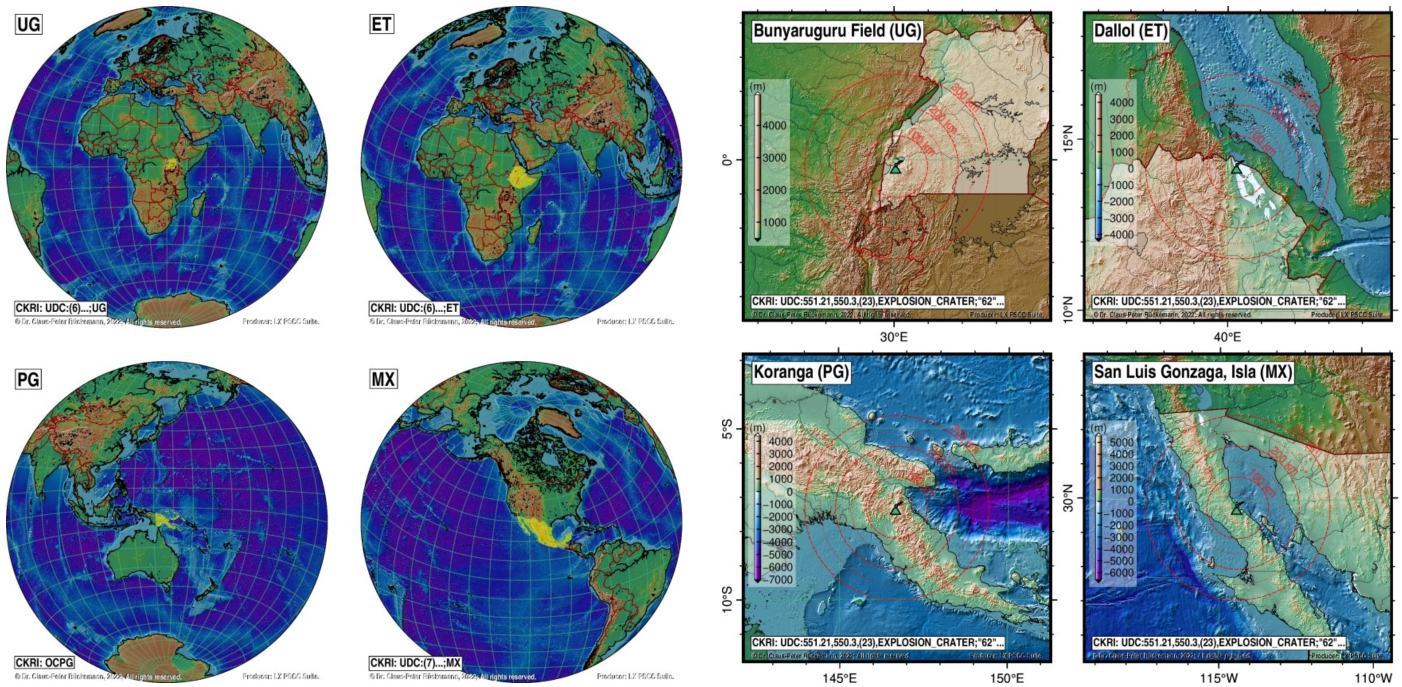
(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 3. Resulting symbolic representation of a volcanological features group facet (shield volcano) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

for implementation is a deep understanding of the knowledge complexity within a discipline, which is represented by the task as well as the required formalisations for all the components.

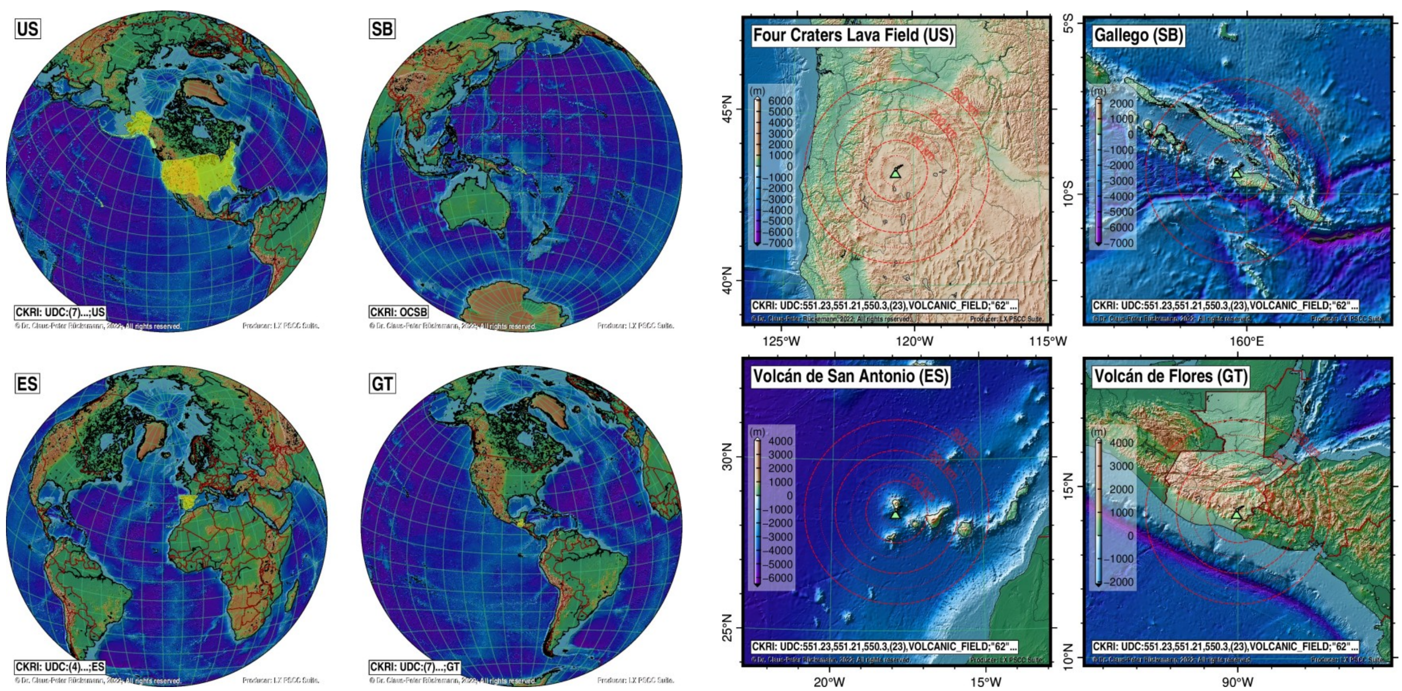
OpenMP is a mature and portable industry standard, which can be efficiently implemented directly by scientists of any discipline in their contextualisation, methodological workflow



(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 4. Resulting symbolic representation of a volcanological features group facet (explosion crater) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

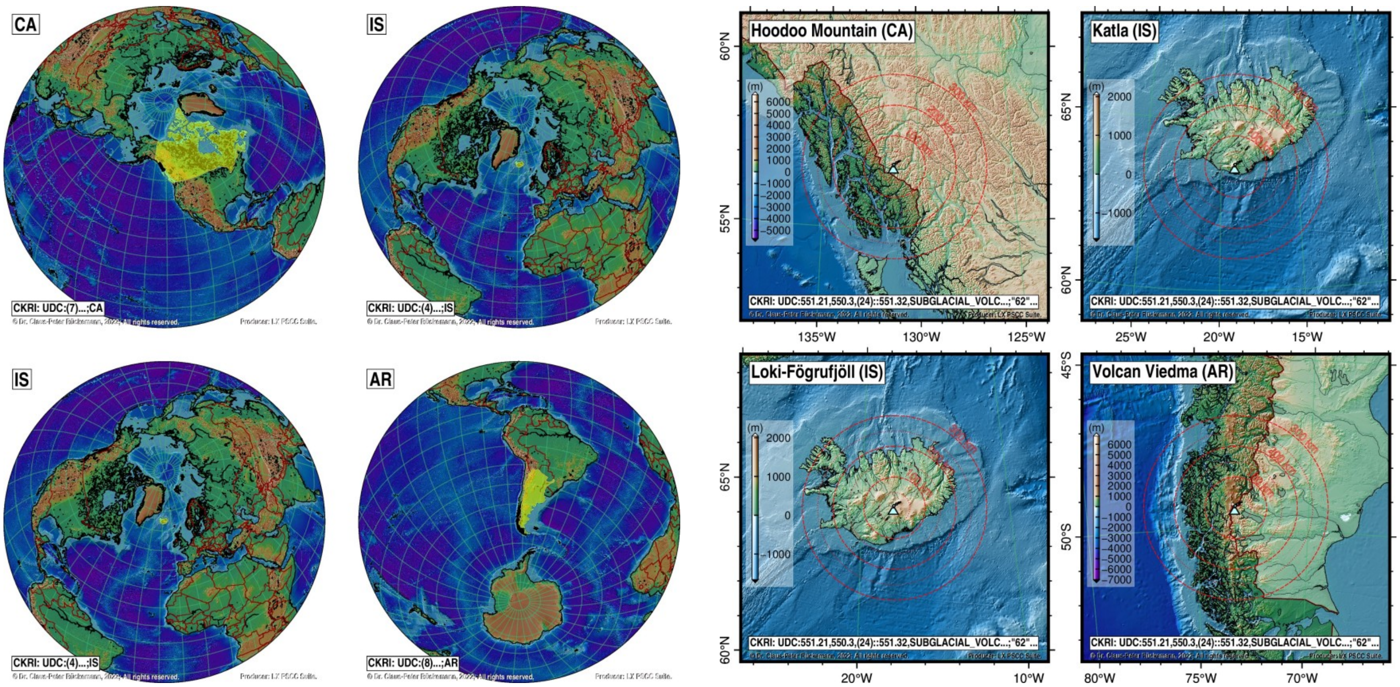


(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 5. Resulting symbolic representation of a volcanological features group facet (volcanic field) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

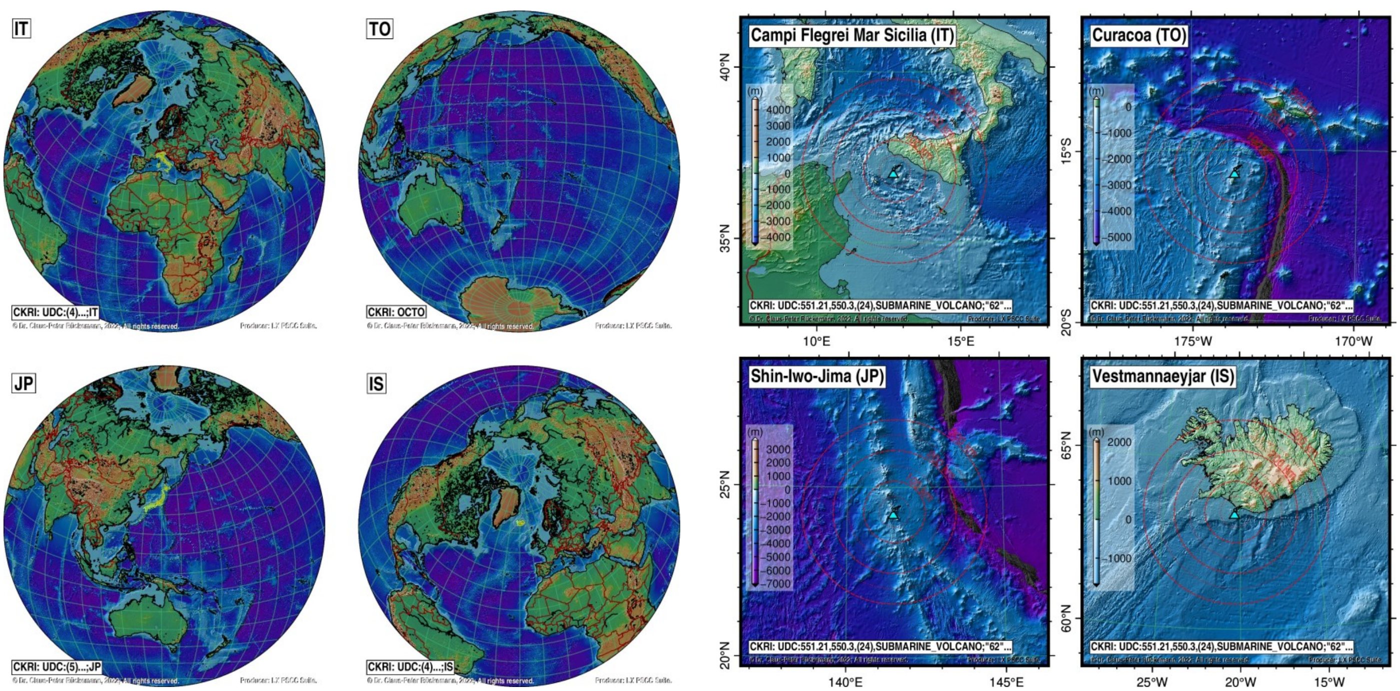
logic, and for their workflow procedure implementations and realisations. Organisation of data structure and formalisation of knowledge are core tasks of a discipline itself and not at all a technical task. Nevertheless, the organisation of knowledge also defines feasible data locality concepts. Parallelisation of workflows with plain-dimension and multi-dimension targets



(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 6. Resulting symbolic representation of a volcanological features group facet (subglacial volcano) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

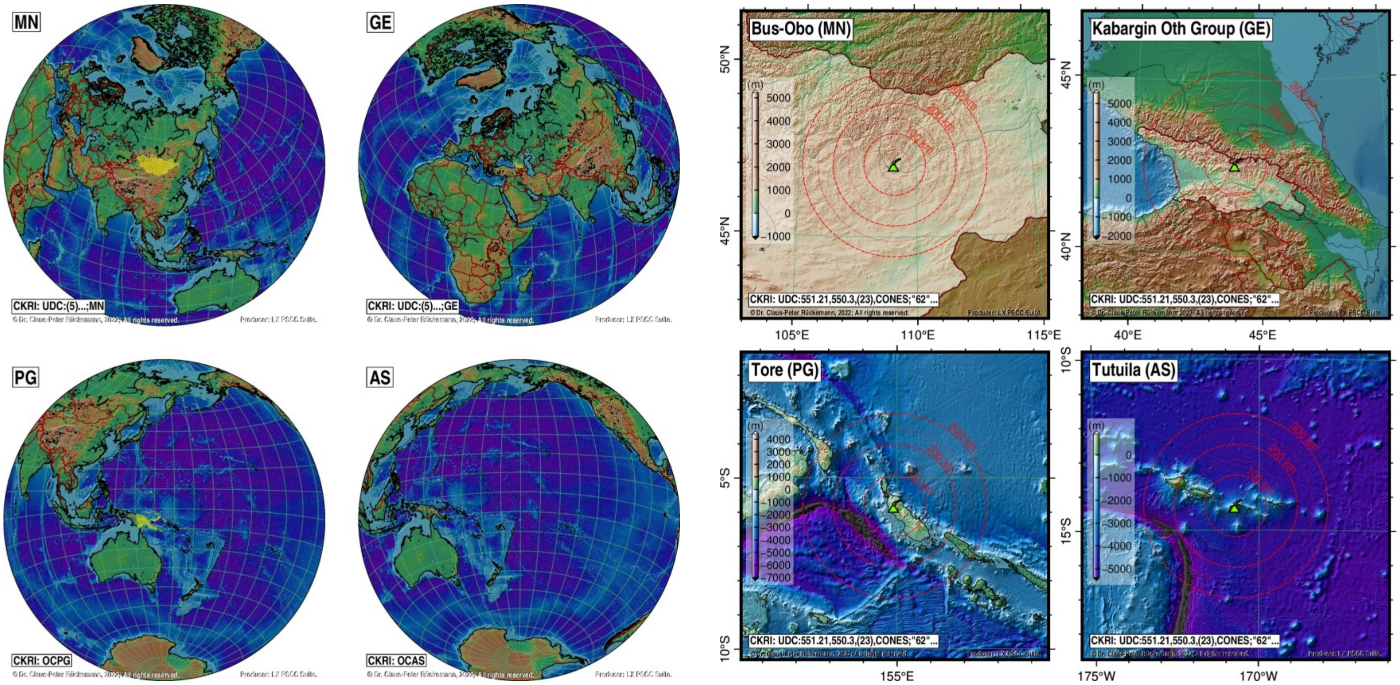


(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 7. Resulting symbolic representation of a volcanological features group facet (submarine volcano) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

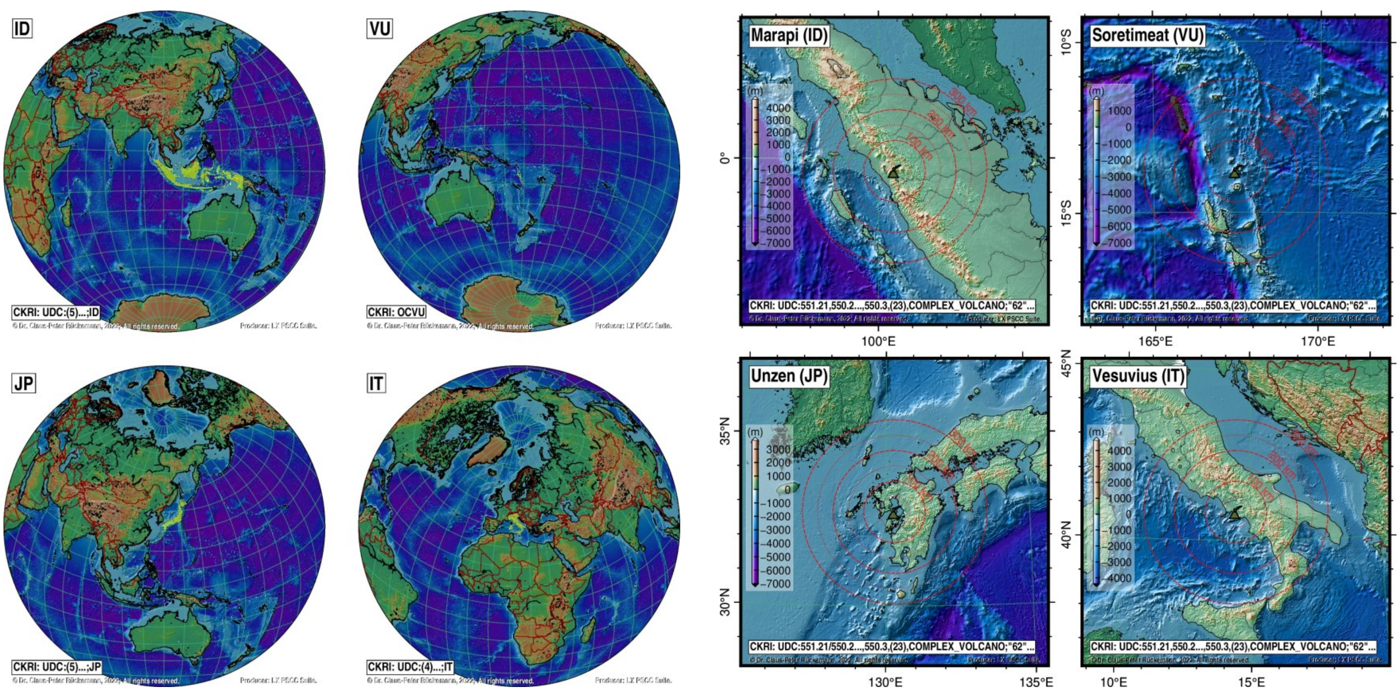
can differ regarding their contextualisation results. For example, a plain-dimension workflow can deliver different contextualisation contexts of an AoI. A multi-dimension workflow can deliver a certain contextualisation context of an AoI, depending on further dimensions, views or chorologies. Therefore, plain- and multi-dimension workflows can complement in



(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 8. Resulting symbolic representation of a volcanological features group facet (cone volcano) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.



(a) Generated symbolic representation of country identification contexts.

(b) Generated symbolic representation of object AoI contexts.

Figure 9. Resulting symbolic representation of a volcanological features group facet (complex volcano) based on coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

chorological and chronological contextualisation while sharing resources, structural and procedural fundaments. Most of the faceting is dealt with in the conceptual processing steps of the workflow. An example for a model reduction in plain-dimension is, e.g., generation of multiple context views. An example for a model reduction in multi-dimension is, e.g.,

TABLE III. INHERENT REPRESENTATION GROUPS WITH INTEGRATED COMPONENTS INVENTORY OBJECT ENTITY EXAMPLE WORKFLOW.

Inherent Representation Group	*Locality-License Model*	*Parallelisation Plain*	*Parallelisation Multi*
KR preprocessing, conceptual	On-premise	Ser. / par.	Ser. / par.
Context preprocessing	Restricted	Ser. / par.	Ser. / par.
KR processing, conceptual	On-premise	OpenMP	OpenMP
Conceptual knowledge processing	On-premise	OpenMP	OpenMP
PoI	On-premise	OpenMP	OpenMP
Point spatial operations	Restricted	OpenMP	OpenMP
Line operations	Restricted	OpenMP	OpenMP
Polygon operations	Restricted	OpenMP	OpenMP
DEM	Restricted	OpenMP	OpenMP
PCRE	Restricted	OpenMP	OpenMP
Editing	Restricted	OpenMP	OpenMP
Projecting	Restricted	OpenMP	OpenMP
Cutting	Restricted	OpenMP	OpenMP
Sampling	Restricted	OpenMP	OpenMP
Filtering	Restricted	OpenMP	OpenMP
Illumination	Restricted	OpenMP	OpenMP
Triangulation	Restricted	OpenMP	OpenMP
Projection	Restricted	OpenMP	OpenMP
Filter operations	On-premise	OpenMP	OpenMP
View/frame computation	Restricted	OpenMP	OpenMP
Model reduction (frames)	n.a.	OpenMP	OpenMP
Model reduction (animation)	n.a.	n.a.	Serial
...	...	...	...

generation of a video of geospherical satellite view frames with moving observer position. It is obvious that the workflow logic of the examples also differ in their ways of parallelisation. The use of on-premise (e.g., in-house) and restricted (distributed) resources is attributable to the licenses of the core assets, the knowledge resources. Inherent representation groups are major matter of scalable processing and conversion (two-dimensional/three-dimensional) and higher multi-dimensional workflow procedures.

Table IV shows the scalability of the example workflow procedure for parallelised parts of the coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups, based on mean requirements for an object entity, with numbers of objects entities, n_o, numbers of frames, n_f, and numbers of views, n_v, for $n_f = 1$ and $n_v = 2$ as in the above symbolic representation example of volcanological features groups.

TABLE IV. PARALLELISED PROCESSING OF INVENTORY WORKFLOW (PARALLELISED KNOWLEDGE RESOURCES AND CONTEXT RESOURCES).

Number of CPU Cores	*Wall Time Workflow (Plain)*	*Number of Object Entities* $n_o = 100$	*Number of Object Entities* $n_o = 500$
1	$n_o \cdot (n_v \cdot n_f \cdot 1,680/1)$ s	336,000 s	1,680,000 s
36	$n_o \cdot (n_v \cdot n_f \cdot 1,680/36)$ s	9,333 s	46,667 s

The architecture choosen for this realisation is an efficient 36-core-based Central Processing Unit (CPU) (Intel Xeon), which is taking into account that we commonly use 36 cores for many basic global approaches, e.g., considering the 360 degrees of a global model. Results on other architectures with same numbers of respective cores will be highly comparable.

Precondition for parallelisation is sufficient memory for parallel use of integrated resources. Considering the employed resources, e.g., SRTM, 128 GB for 36 parallel processes is comfortable when data limits are cut to the limits required for the algorithms with the range of a few hundred kilometres area per object entity.

Wall and compute times, especially of multi-dimensional workflow results, can greatly be reduced from the integrated parallelisation, which makes the procedural solution highly scalable. The wall times for numbers of objects entities, n_o, illustrate the high scalability when the same workflow is using higher numbers of CPU cores. Probably, most practical workflows may contain parts which cannot be reasonably parallelised. This is especially true for scientific tasks with a certain complexity. The percentage of non parallelised parts is very low here. For multi-dimension targets, e.g., animations with $n_f = 1000$ and $n_v = 1$, it may be considered to employ hundreds to thousands of CPU cores so parallelised wall times per object can be reduced from days to hours.

That means, for the scenario and inventory subset displayed in this publication all the symbolical representation, contextualisation, and visualisation can be continuously assembled and updated based on highest resolution satellite data and continuously updated Knowledge Resources on one processor in less than an hour now with the given compute resources. Anyhow, workflow time consumption may be non-linear, depending on the reflected scenario and present status of integrated resources.

Serial and parallel compute times, e.g., for groups of object entities, are non-linear. For example, mean times for the same workflow realisation may greatly differ for different object entities. To significant extent, this is consequence of the inherent complexity of the knowledge complements, which have to be integrated and analysed. In practice, compute times for object entities may commonly vary to over several hundred percent. Component and knowledge contributions of different disciplines may have different weight in their contributions to the non-linearities. The resulting compute times may even deliver continuously new and non-linear compute times in a dynamical workflow realisation with knowledge resources and components, which are in continuous development.

In principle two basic constellation categories exist here with multi-dimensional results, temporal static and positional static. Including faceting, both categories can be fully parallelised regarding view/frame computation, e.g., via OpenMP.

The compute requirements are about the same for both categories, mostly depending on the parametrisation of used resources and components, including faceting. Nevertheless, due to the characteristics and diversity of real scenarios and environments the compute requirements differ to some extend with the targeted chorology and chronology. Levels of effective parallelisation may differ due to amounts of data to be processed, e.g., satellite and model data. Compute intensities depend on the target object entity, too, not only on an object group facet.

In addition, processing, analysis, and conversion requirements may also largely depend on the number and complexity of vector objects in the respective object entity contexts. At least if preprocessing, e.g., resizing, scaling, and resampling, is not common to more than one target, e.g., a frame in one of either categories, that part of the processing should be done once in a sub-loop only and not in parallelisation.

For organisational reasons with discipline related knowledge development processes, every loop might require an individual preprocessing, which might not be possible to be parallelised or requires a decoupled parallelisation. These aspects, discipline related knowledge development and faceting, are addressing methodological principles and should be dealt with by members of the responsible discipline, e.g., from archaeology.

Anyhow, commonly this preprocessing is a minor computational effort of less then a few percent overall but essential for the contextualisation.

V. Conclusion

The new approaches for the creation of a sustainable procedural component framework for implementation and realisation of a coherent multi-disciplinary conceptual knowledge-based inventory and faceting proved efficient and sustainable. Based on the methodology of coherent conceptual knowledge classification, the CKRI, and the CRI frameworks, the procedural and conceptual implementation and realisation of a Holocene-prehistoric inventory of worldwide volcanological features groups facets showed very flexible and scalable, supported by many scenarios over the last years. The developed framework of components, can be employed for multi-disciplinary integration of knowledge contexts. Everything has been done to deploy standards and provide maximum flexibility so that context from prehistory, archaeology, natural sciences, and humanities can be be coherently integrated. The methodology of coherent conceptual knowledge contextualisation and its implemented methods proved to enable coherent context integration in prehistory and archaeology, sustainable, advanced contextualisation [36] and method integration [37], e.g., for prehistorical and classical archaeology and their multi-disciplinary contexts. The component framework showed to enable an effective and efficient coherent multi-disciplinary conceptual knowledge contextualisation and georeferenced symbolic representation and proved most scalable and sustainable during all long-term development and practical use.

Researchers from all disciplines already practice the procedural component framework development, coherent conceptual knowledge, and procedure parallelisation in professional long-term research knowledge and data management.

Together with the corresponding conceptual knowledge reference implementation, the CRI framework of components will on long-term be employed in a wide range of disciplines and different ongoing projects in prehistorical and classical archaeology and multi-disciplinary contextualisation.

The methodology enables the practical contextualisation and integration of knowledge, supporting systematical and methodological backprojections for disciplines employing their methods in interaction with future multi-dimensional and multi-disciplinary knowledge models and symbolic representations.

Future research will address the creation of a component framework for further developing the Holocene-prehistoric inventory of worldwide volcanological features, which enables coherent multi-disciplinary conceptual knowledge facets and procedural integration and coherent multi-disciplinary conceptual knowledge contextualisation with prehistorical and archaeological knowledge resources and new advanced multi-dimensional context integration models.

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Faceting the Holocene-prehistoric Inventory of Volcanological Features Groups

Towards Sustainable Multi-disciplinary Context Integration in Prehistory and Archaeology Based on the Methodology of Coherent Conceptual Knowledge Contextualisation

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Abstract—**This paper presents extended research and current status on a practical solution for geoscientific inventories based on conceptual contextualisation. The goal of this research is the creation and further development of a practical Holocene-prehistoric inventory of worldwide volcanological features groups, coherently integrating multi-disciplinary conceptual knowledge. The focus is a sustainable multi-disciplinary integration of knowledge contexts, especially from prehistory and archaeology, which further enables coherent multi-disciplinary conceptual knowledge contextualisation and georeferenced symbolic representation. This paper provides the status of conceptual knowledge facets, implementations and realisations of the coherent conceptual knowledge and the methodological component integration. The resulting inventory is illustrated by resulting excerpts of major volcanological features groups based on a conceptual knowledge result matrix. Future research will address the resulting Holocene-prehistoric inventory of worldwide volcanological feature groups, continuous development of resources and integration and coherent multi-disciplinary conceptual knowledge contextualisation with prehistorical and archaeological knowledge resources for creation of new insight.**

***Keywords*–Holocene-prehistoric Inventory of Volcanological Features Groups; Contextualisation; Coherent Multi-disciplinary Conceptual Knowledge Faceting and Integration; CKRI; CRI Framework.**

I. Introduction

This paper is an extended and updated presentation of the research based on the publication and presentation at the GEOProcessing 2022 conference in Porto, Portugal [1]. Due to a number of recent requests for the created inventory, we take the chance that this extended paper can concentrate on the practical inventory, showing a wider range of result groups based on practical conceptual facets used for on-demand contextualisation and symbolic representation.

The corresponding procedural component framework implementation and realisation for creation of a multi-disciplinary coherent conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups is described in detail [2] along with the overall frame [3] and importance of information science methods and structures [4]. Faceting aspects employing procedural components is provided with an extended view on implementations [5].

The goal of this research is the creation and further development of a practical Holocene-prehistoric inventory of worldwide volcanological features groups, integrating arbitrary coherent conceptual knowledge. The target is a sustainable multi-disciplinary integration of knowledge contexts, especially from prehistory and archaeology, which further enables a coherent conceptual knowledge contextualisation and georeferenced symbolic representation. The approach conforms with information science fundaments and universal knowledge, which enable an integration of the required components from methodologies to realisations for knowledge representations of realia and abstract contexts [6], considering that many facets of knowledge, including prehistory, need to be continuously acquired and reviewed [7]. Creating contextualisation requires to coherently integrate multi-disciplinary knowledge and to enable symbolic representations, e.g., integrating chorological and chronological contexts. Realisations need to integrate a wide range of components as required from participating disciplines, e.g., for dynamical processing, geoprocessing, spatial contextualisation. Implementation and realisation based on the methodology of coherent conceptual knowledge contextualisation requires the integration of standardised, modular components required for task within participating disciplines. This research employs knowledge resources, data sources, and Points of Interest (PoI), especially Knowledge Resources (KR) focussing on volcanological features, prehistory, and archaeology.

Therefore, two major reference implementations were deployed for implementation, realisation, and continuous further development: The Conceptual Knowledge Reference Implementation (CKRI) [8] and the Component Reference Implementations (CRI) framework [9]. The reference implementations were created with coherent conceptual knowledge and sustainable standardised components in mind.

The rest of this paper is organised as follows. Section II presents the major reference implementations. Section III presents the methodological implementation and realisation with the CKRI references and the respective component integration for this research. Section IV shows the resulting inventory, the knowledge integration results, and excerpts of the created volcanological features groups of the inventory. Section V provides a compact discussion of the results regarding the coherent conceptual knowledge integration. Section VI summarises lessons learned, conclusions, and future work.

II. Major reference implementations

The coherent knowledge resources and the practical realisation are fully based on the main implementations of the prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI) [8] and the Component Reference Implementations (CRI) framework [9]. CKRI provides the knowledge framework, including multi-disciplinary contexts of natural sciences and humanities [10]. CRI provides the required component groups and components for the implementation and realisation of all the procedural modules. The component and workflow procedure related research for this inventory is in focus of multi-disciplinary research groups and matter to be reported in separate publications. Many aspects of knowledge [11], including meaning, can be described using knowledge complements supporting a modern definition of knowledge [12] and subsequent component instrumentation, e.g., considering factual, conceptual, procedural, metacognitive, and structural knowledge.

Especially, conceptual knowledge can relate to any of factual, conceptual, procedural, and structural knowledge. Knowledge complements are a means of understanding and targeting new insight, e.g., enabling advanced contextualisation, integration, analysis, synthesis, innovation, prospection, and documentation. Regarding knowledge, it should be taken for granted, that scientific members of any disciplines nowerdays continuously practice and train themselves in development and practical employment of methods, algorithms, and components as required by their disciplines and keep track with how to integrate methods. All the components are in continuous development by the respective disciplines themselves.

The reference implementations are part of the developments and provide sustainable, flexible, and efficient fundaments for solutions targeting the creation of coherent multi-disciplinary conceptual knowledge contextualisation.

III. Methodological implementation and realisation

Implementation and realisation are based on the CKRI reference implementation [8], and respective contextualisation. Components outside the core scope of this knowledge focussed geoscientific, prehistoric, and archaeological research are employed and can be extended via the CRI frame reference implementations [9]. Both provide sustainable fundaments for highest levels of reproducibility and standardisation.

A. Resulting coherent conceptual knowledge implementation

Universally consistent multi-disciplinary conceptual knowledge is based on the Conceptual Knowledge Reference Implementation (CKRI) [8] and implemented via UDC code references for demonstration, spanning the main tables [13] shown in Table I and major discipline knowledge, ‘natural sciences’ (Table II) and ‘history’ (Table III).

Table I. CKRI implementation of coherent conceptual knowledge contextualisation; main tables.

Code / Sign Ref.	*Verbal Description (EN)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information. Documentation. Librarianship. Institutions. Publications
UDC:1	Philosophy. Psychology
UDC:2	Religion. Theology
UDC:3	Social Sciences
UDC:5	Mathematics. Natural Sciences
UDC:6	Applied Sciences. Medicine, Technology
UDC:7	The Arts. Entertainment. Sport
UDC:8	Linguistics. Literature
UDC:9	Geography. Biography. History

Table II. CKRI implementation of coherent conceptual knowledge contextualisation: . . . natural sciences (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:5	Mathematics. Natural Sciences
UDC:52	Astronomy. Astrophysics. Space research. Geodesy
UDC:53	Physics
UDC:539	Physical nature of matter
UDC:54	Chemistry. Crystallography. Mineralogy
UDC:55	Earth Sciences. Geological sciences
UDC:550.3	Geophysics
UDC:551	General geology. Meteorology. Climatology. Historical geology. Stratigraphy. Palaeogeography
UDC:551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena. Eruptions
UDC:551.2. . .	Fumaroles. Solfataras. Geysers. Hot springs. Mofettes. Carbon dioxide vents. Soffioni
UDC:551.44	Speleology. Caves. Fissures. Underground waters
UDC:551.46	Physical oceanography. Submarine topography. Ocean floor
UDC:551.7	Historical geology. Stratigraphy
UDC:551.8	Palaeogeography
UDC:56	Palaeontology

Table III. CKRI implementation of coherent conceptual knowledge contextualisation: . . . history (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:9	Geography. Biography. History
UDC:902	Archaeology
UDC:903	Prehistory. Prehistoric remains, artefacts, antiquities
UDC:904	Cultural remains of historical times

Table IV shows an excerpt of consistent multi-disciplinary conceptual knowledge based on UDC code references spanning auxiliary tables [14].

Table IV. CKRI implementation of coherent conceptual knowledge contextualisation: Auxiliary tables (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC (1/9)	Common auxiliaries of place
UDC:(23)	Above sea level. Surface relief. Above ground generally. Mountains
UDC:“...”	Common auxiliaries of time.
UDC:“6”	Geological, archaeological and cultural time divisions
UDC:“62”	Cenozoic (Cainozoic). Neozoic (70 MYBP - present)
UDC:“63”	Archaeological, prehistoric, protohistoric periods and ages

The employed CKRI corresponds with development stage editions, prehistory-protohistory and archaeology E.0.4.8, natural sciences E.0.4.0).

The CKRI implementations provide the fundament for the coherent multi-disciplinary knowledge based integration and the realisations of the methodological component integration.

B. Resulting methodological component integration

Integration components, reflecting standards and sustainable modules are based on the major groups of the Component Reference Implementations (CRI) frame [9]. The employed CRI framework corresponds with development stage edition E.0.3.9.

The ten major CRI component groups were integrated for the implementation and realisation of the practical Holocene-prehistoric inventory of volcanological features groups.

In summary, with this short excursus on procedural components here, the main component groups are focussing on:

1) Conceptual knowledge frameworks.
2) Conceptual knowledge base.
3) Integration of scientific reference frameworks.
4) Formalisation.
5) Methodologies and workflows integration.
6) Prehistory Knowledge Resources.
7) Natural Sciences Knowledge Resources.
8) Inherent representation groups.
9) Scientific context parametrisation.
10) Structures and symbolic representation.

Focus is on the contextualisation and conceptual knowledge framework, its development, and its flexibility of integration with advanced components. All component groups are supporting conceptual knowledge and respective faceting.

Relevant pre-existing and ongoing component developments addressing knowledge with multi-disciplinary KR have been summarised [15]. Integration of components and procedural realisations are out of scope here but subject of research in respective fields. Procedural realisations will therefore be published separately.

The exact components for the implementation and realisation of the practical Holocene-prehistoric inventory of volcanological features groups are given in the next sections.

IV. Resulting inventory and faceting

The following sections provide illustrative object entity examples of the new practical Holocene-prehistoric inventory of volcanological features groups facets as implemented and realised integrating the aforementioned reference implementations. Figure V shows an excerpt of respective features groups facets and their chronological and context references respective volcanic activities and contexts resulting from the resources.

Table V. Holocene-prehistoric Volcanological features group facets (excerpt), Holocene-prehistoric corresponding with Prehistoric Volcanic Activity.

Volcanological Features Group	*Volcanic Activity*	*Context Example*
Strato volcano	Holocene	PVA
Maars features	Holocene	PVA
Shield volcano	Holocene	PVA
Explosion crater	Holocene	PVA
Volcanic field	Holocene	PVA
Subglacial volcano	Holocene	PVA
Submarine volcano	Holocene	PVA
Cones	Holocene	PVA
Complex volcano	Holocene	PVA

Context example references for the Holocene-prehistoric Inventory of volcanological features groups are Prehistoric Volcanic Activity (PVA) for all volcanological features groups. These features groups facets provide a base for the conceptual knowledge facets. The context examples will be discussed in more detail the following, presenting the result matrix of facets and contexts.

A. *Resulting coherent conceptual knowledge facets integration*

The coherent conceptual knowledge integration enables facet creation and multi-disciplinary conceptual knowledge integration. This case demonstrates an integration of Holocene-prehistoric volcanological features, geoscientific knowledge, and spatial knowledge. Any further knowledge can be coherently integrated, e.g., prehistoric and archaeological knowledge.

Table VI shows an excerpt of the result matrix of Holocene-prehistoric volcanological features groups and respective facets, namely conceptual knowledge, chronology, and chorology. The result matrix includes conceptual knowledge view groups [16] based on CKRI references [8], factual knowledge from the Knowledge Resources objects, and respective country codes.

Context example references for the features groups facets show Prehistoric Volcanic Activity (PVA), Historic Volcanic Activity (HVA), and Continued Volcanic Activity (CVA), e.g., latent volcanic activity. PVA are consequence of the Holocene-prehistoric target for all objects in the resulting volcanological features groups. Cases for which further facts are holding true can also allow past-prehistoric contextualisation, e.g., with HVA and CVA. Multi-disciplinary contextualisation further depends on the availability of respective factual knowledge, e.g., via The Prehistory and Archaeology Knowledge Archive (PAKA) [17]. Any case can be dynamically contextualised with multi-disciplinary knowledge, especially from prehistory and archaeology, e.g., referring to prehistoric object properties and excavation results and targeting new insight from geoscientific and multi-disciplinary context integration. The methodology enables to create methods as displayed in the following sections, supporting many features required for integration and analysis, e.g., semi-automated referencing, chorology faceting, chronology faceting, multi-disciplinary contexts, and creation of result matrices.

The result matrices and facets reflect the key assets with the CRI framework [9] to realise the inventory and symbolic representations and to enable a continuous development.

B. *Resulting symbolic representation of features groups facets*

Figure 1 shows a resulting symbolic representation of a volcanological features group, strato volcano, as based on the coherent conceptual knowledge integration. Generated representations include integrated CKRI references, projection of bathymetric and topographic results, and further knowledge for respective areas. The symbolic representation enables the signification of the different facets. Here distinctly coloured volcano symbols represent the volcanological features groups and respective conceptual knowledge facets in the visualisation of the result matrix objects. Figure 2 shows a resulting symbolic representation of a volcanological features group, maars, as based on the coherent conceptual knowledge integration. The views of the result matrix further include the conceptual knowledge features groups facets of shield volcanoes (Figure 3), explosion craters (Figure 4), volcanic fields (Figure 5), subglacial volcanoes (Figure 6), submarine volcanoes (Figure 7), cones (Figure 8), and complex volcanoes (Figure 9).

The resulting symbolic representations reflect the coherent conceptual knowledge (CKRI, UDC references) and bathymetric and topographic knowledge (CRI components). Projection

TABLE VI. RESULT MATRIX OF HOLOCENE-PREHISTORIC VOLCANOLOGICAL FEATURES GROUPS FACETS (EXCERPT). IT INCLUDES CONCEPTUAL KNOWLEDGE VIEW GROUPS [16] (CKRI), VOLCANIC ACTIVITY, CONTEXTS, KNOWLEDGE RESOURCES OBJECTS, AND COUNTRY CODES (EXCERPT).

Multi-disciplinary Conceptual Knowledge Facets	*Chronology Facets*		*Chorology Facets*	
Volcanological Features Conceptual Knowledge View / Facets Group	*Volcanic Activity*	*Context*	*Knowledge Resources Object*	*Country Code*
CKRI: UDC:551.21,550.3,(23),STRATO_VOLCANO;"62"...	Holocene	PVA / HVA	Agua de Pau	PT
CKRI: UDC:551.21,550.3,(23),STRATO_VOLCANO;"62"...	Holocene	PVA	Alngey	RU
CKRI: UDC:551.21,550.3,(23),STRATO_VOLCANO;"62"...	Holocene	PVA / HVA	Azuma	JP
CKRI: UDC:551.21,550.3,(23),STRATO_VOLCANO;"62"...	Holocene	PVA / HVA	Hekla	IS
CKRI: UDC:551.21,550.3,(23),STRATO_VOLCANO;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.2...,551.21,550.3,(23),...MAARS_FEATURES;"62"...	Holocene	PVA	Cerro Tujle	CL
CKRI: UDC:551.2...,551.21,550.3,(23),...MAARS_FEATURES;"62"...	Holocene	PVA / HVA	Suoh	ID
CKRI: UDC:551.2...,551.21,550.3,(23),...MAARS_FEATURES;"62"...	Holocene	PVA / HVA	Ukinrek Maars	US
CKRI: UDC:551.2...,551.21,550.3,(23),...MAARS_FEATURES;"62"...	Holocene	PVA / (CVA)	West Eifel Volcanic Field	DE
CKRI: UDC:551.2...,551.21,550.3,(23),...MAARS_FEATURES;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.21,550.3,(23),SHIELD_VOLCANO;"62"...	Holocene	PVA / (CVA)	Volcán Darwin	EC
CKRI: UDC:551.21,550.3,(23),SHIELD_VOLCANO;"62"...	Holocene	PVA / HVA	Kilauea	US
CKRI: UDC:551.21,550.3,(23),SHIELD_VOLCANO;"62"...	Holocene	PVA / HVA	Santorini	GR
CKRI: UDC:551.21,550.3,(23),SHIELD_VOLCANO;"62"...	Holocene	PVA	Waesche	AQ
CKRI: UDC:551.21,550.3,(23),SHIELD_VOLCANO;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.21,550.3,(23),EXPLOSION_CRATER;"62"...	Holocene	PVA / (CVA)	Bunyaruguru Field	UG
CKRI: UDC:551.21,550.3,(23),EXPLOSION_CRATER;"62"...	Holocene	PVA / HVA	Dallol	ET
CKRI: UDC:551.21,550.3,(23),EXPLOSION_CRATER;"62"...	Holocene	PVA	Koranga	PG
CKRI: UDC:551.21,550.3,(23),EXPLOSION_CRATER;"62"...	Holocene	PVA	San Luis Gonzaga, Isla	MX
CKRI: UDC:551.21,550.3,(23),EXPLOSION_CRATER;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.23,551.21,550.3,(23),VOLCANIC_FIELD;"62"...	Holocene	PVA	Four Craters Lava Field	US
CKRI: UDC:551.23,551.21,550.3,(23),VOLCANIC_FIELD;"62"...	Holocene	PVA	Gallego	SB
CKRI: UDC:551.23,551.21,550.3,(23),VOLCANIC_FIELD;"62"...	Holocene	PVA / HVA	Volcán de San Antonio	ES
CKRI: UDC:551.23,551.21,550.3,(23),VOLCANIC_FIELD;"62"...	Holocene	PVA	Volcán de Flores	GT
CKRI: UDC:551.23,551.21,550.3,(23),VOLCANIC_FIELD;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.21,550.3,(24)::551.32,SUBGLACIAL_VOLC...;"62"...	Holocene	PVA	Hoodoo Mountain	CA
CKRI: UDC:551.21,550.3,(24)::551.32,SUBGLACIAL_VOLC...;"62"...	Holocene	PVA / HVA	Katla	IS
CKRI: UDC:551.21,550.3,(24)::551.32,SUBGLACIAL_VOLC...;"62"...	Holocene	PVA / HVA	Loki-Fögrufjöll	IS
CKRI: UDC:551.21,550.3,(24)::551.32,SUBGLACIAL_VOLC...;"62"...	Holocene	PVA / HVA	Volcan Viedma	AR
CKRI: UDC:551.21,550.3,(24)::551.32,SUBGLACIAL_VOLC...;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.21,550.3,(24),SUBMARINE_VOLCANO;"62"...	Holocene	PVA / HVA	Campi Flegrei Mar Sicilia	IT
CKRI: UDC:551.21,550.3,(24),SUBMARINE_VOLCANO;"62"...	Holocene	PVA / HVA	Curacoa	TO
CKRI: UDC:551.21,550.3,(24),SUBMARINE_VOLCANO;"62"...	Holocene	PVA / HVA	Shin-Iwo-Jima	JP
CKRI: UDC:551.21,550.3,(24),SUBMARINE_VOLCANO;"62"...	Holocene	PVA / HVA	Vestmannaeyjar	IS
CKRI: UDC:551.21,550.3,(24),SUBMARINE_VOLCANO;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.21,550.3,(23),CONES;"62"...	Holocene	PVA	Bus-Obo	MN
CKRI: UDC:551.21,550.3,(23),CONES;"62"...	Holocene	PVA	Kabargin Oth Group	GE
CKRI: UDC:551.21,550.3,(23),CONES;"62"...	Holocene	PVA	Tore	PG
CKRI: UDC:551.21,550.3,(23),CONES;"62"...	Holocene	PVA	Tutuila	AS
CKRI: UDC:551.21,550.3,(23),CONES;"62"...	Holocene	PVA	...	...
CKRI: UDC:551.21,550.2...,550.3,(23),COMPLEX_VOLCANO;"62"...	Holocene	PVA / HVA	Marapi	ID
CKRI: UDC:551.21,550.2...,550.3,(23),COMPLEX_VOLCANO;"62"...	Holocene	PVA / HVA	Soretimeat	VU
CKRI: UDC:551.21/550.2...,550.3,(23),COMPLEX_VOLCANO;"62"...	Holocene	PVA / HVA	Unzen	JP
CKRI: UDC:551.21,550.2...,550.3,(23),COMPLEX_VOLCANO;"62"...	Holocene	PVA / HVA	Vesuvius	IT
CKRI: UDC:551.21,550.2...,550.3,(23),COMPLEX_VOLCANO;"62"...	Holocene	PVA	...	...
...	...	...	...	...

for all representations is Lambert Azimuthal Equal Area. Ellipsoid is World Geodetic System 84 (WGS-84). The conceptual knowledge references correspond with the symbolism, e.g., automatic assignment of symbols, e.g., volcano symbols or different colours for different volcanological features groups and facets.

These features groups integrate bathymetric and topographic knowledge, for example. Here, available multi-disciplinary knowledge can be used for contextualisation, e.g., representing characteristics, physical properties, plate tectonics, soil, and age. Further features allow analysis of contexts, e.g., prehistorical and archaeological properties, continentality regime, coast line dependences, and coast distance. The conceptual knowledge view groups of object entities of Holocene-prehistoric volcanological features groups correspond with the result matrix (Table VI).

Entities of each features group refer to any further available volcanological knowledge, e.g., factual knowledge. In these excerpts, the symbolic representations include the calculated object labels, calculated country codes, distance markers up to 300 km in 50 km steps, and calculated country height range of bathymetry / topography.

The generated symbolic representations can integrate most recent knowledge (e.g., factual, conceptual, procedural, metacognitive, structural) contributed by disciplines and can therefore consider multi-disciplinary results and findings in order to create conceptual knowledge references and new insight.

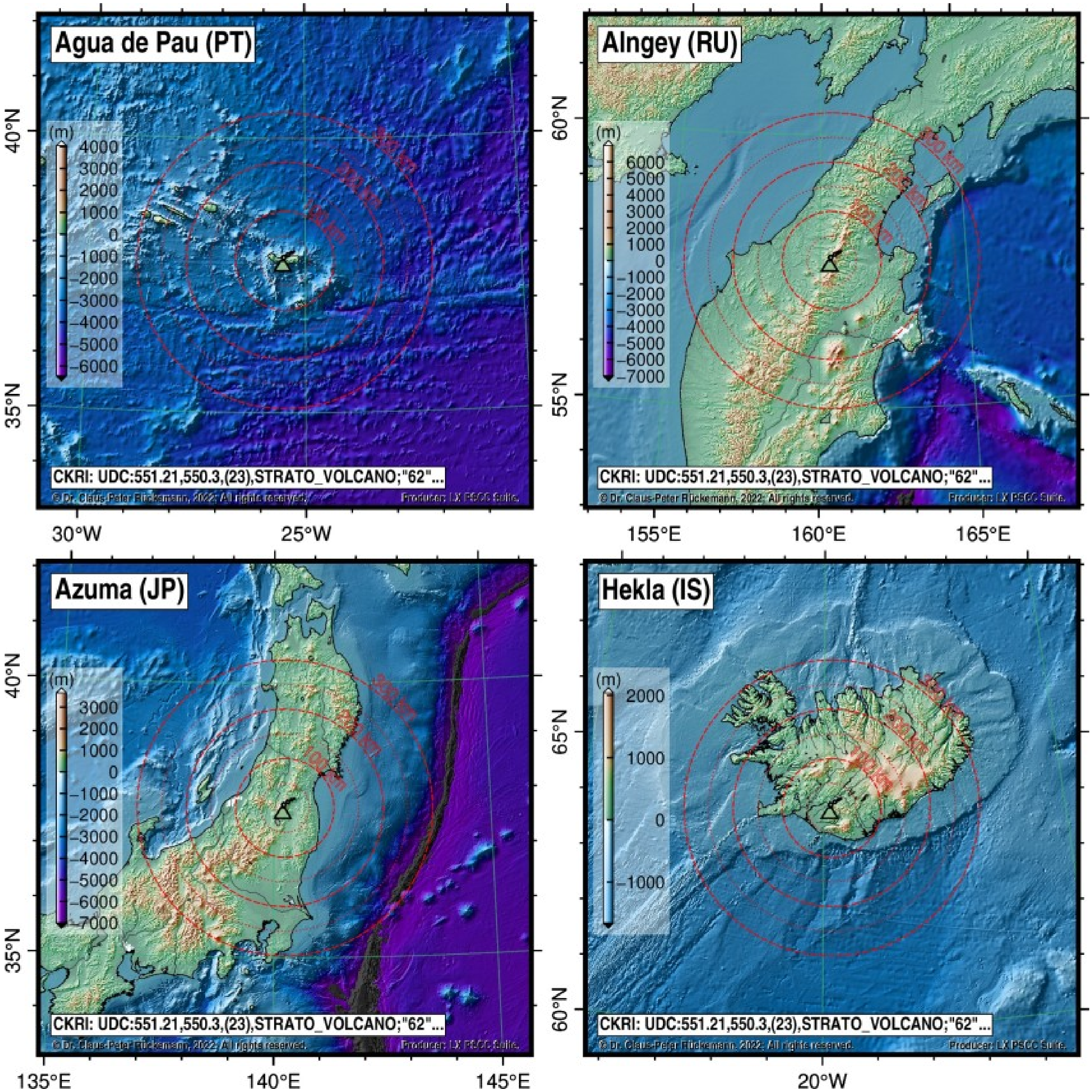

Figure 1. Resulting symbolic representation of a volcanological features group facet (strato volcano) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

V. Components integrated for implementation and realisation

The following passages give a compact overview of major component implementations and development integrated with this research. More detailed, comprehensive discussion and examples regarding fundaments are available with the references on methodology, contextualisation, and conceptual knowledge.

The created and further developed reference implementations of conceptual knowledge frameworks (this research major references in Tables I and IV) are used with the implementation and realisation *KR* [15].

Conceptual knowledge base is The *Universal Decimal Classification (UDC)* [16], a general plan for knowledge classification, providing an analytico-synthetic and *faceted* classification, designed for subject description and indexing of content of information resources *irrespective of the carrier, form, format, and language*. UDC-based references for demonstration are taken from the multi-lingual UDC summary [16] released by the UDC Consortium, Creative Commons license [18].

Relevant scientific practices, frameworks, and standards from disciplines and contexts are integrated with the Knowledge Resources, e.g., here details regarding volcanological

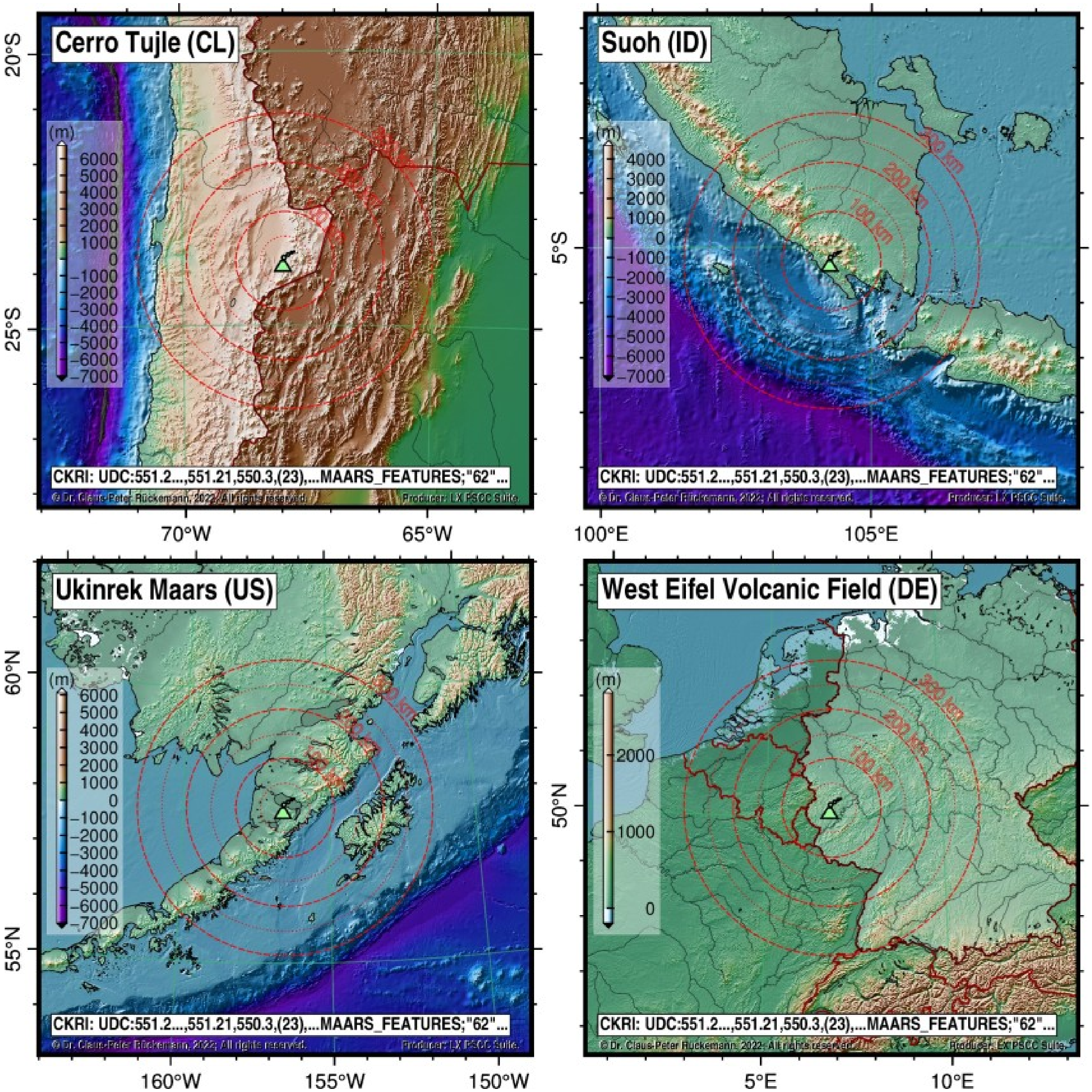

Figure 2. Resulting symbolic representation of a volcanological features group facet (maars) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

features [19], chronologies, spatial information, and Volcanic Explosivity Index (VEI) [20].

All integration components, for all disciplines, require an *explicit and continuous formalisation* [21] *process*. The formalisation includes computation model support, e.g., *parallelisation standards, OpenMP* [22], Reg Exp patterns, e.g., *Perl Compatible Regular Expressions (PCRE)* [23].

Methodologies for creating and utilising methods include model processing, remote sensing, spatial mapping, high information densities, and visualisation. Respective contextualisation of (prehistoric) scenarios should each be done under specific (prehistoric) conditions, especially supported by state-of-the-art methods, e.g., spatial operations, triangulation, gradient computation, and projection.

The symbolic representation of the contextualisation can be done with a wide range of methods, algorithms, and available components, e.g., via LX Professional Scientific Content-Context-Suite (LX PSCC Suite) [24] deploying the Generic Mapping Tools (GMT) [25] for visualisation.

Prehistoric objects and contexts are taken from *The Prehistory and Archaeology Knowledge Archive (PAKA)*, in continuous development for more than three decades [26] and is

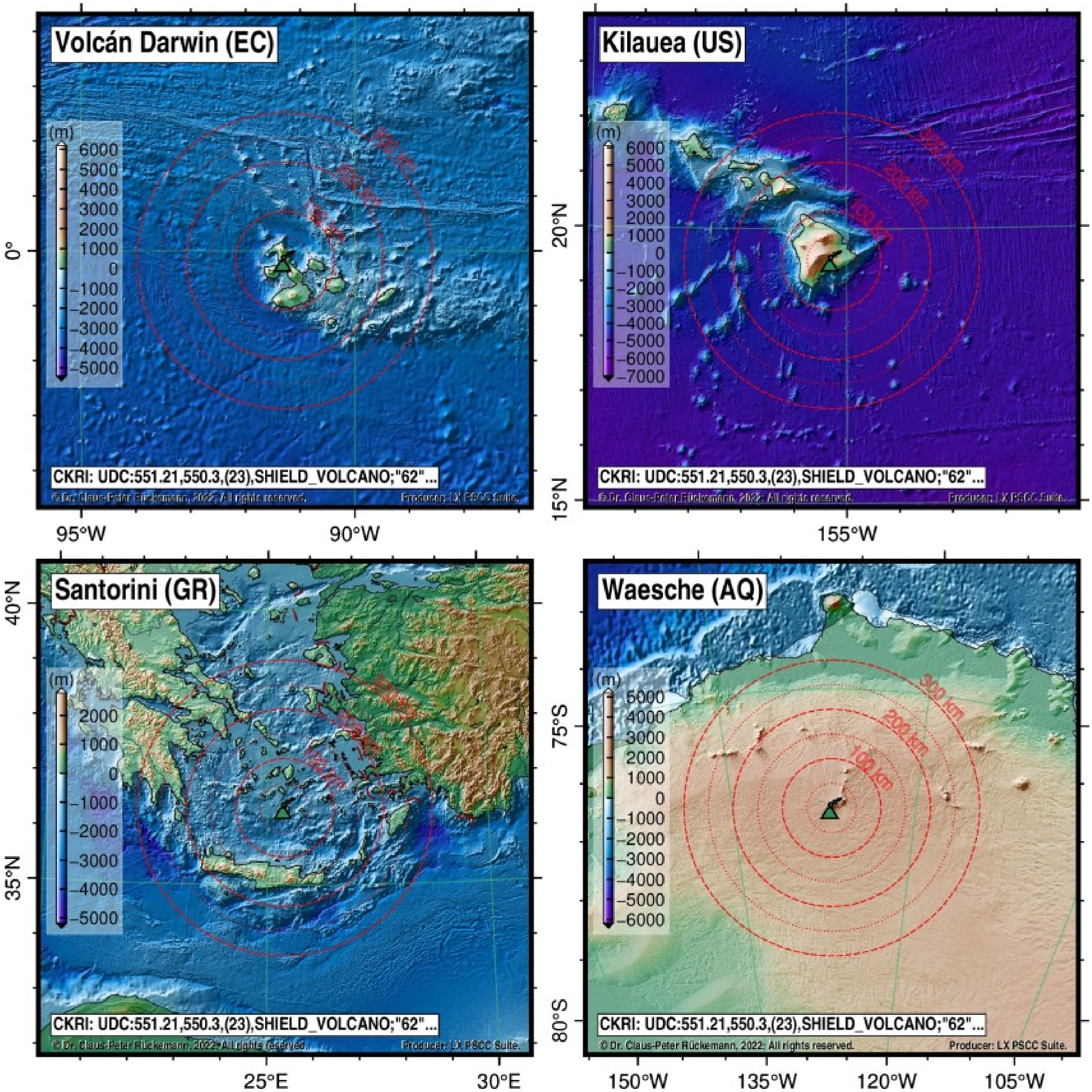

Figure 3. Resulting symbolic representation of a volcanological features group facet (shield volcano) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

released by DIMF for the previous working edition [17] and the contributions for this work [27].

Several coherent systems of major natural sciences' context object groups from *KR realisations* have been implemented, especially Knowledge Resources focussing on volcanological features [20] deployed with in depth contextualisation [19] and with a wide range [16] of contexts [15] and structures [28].

The contextualisation for the inventory can employ state-of-the-art results from many disciplines, e.g., context from the natural sciences resources, integrating their inherent representation and common utilisation, e.g., *points*, *polygons*, *lines*, *Digital Elevation Model (DEM), Digital Terrain Model (DTM), and Digital Surface Model (DSM) representations* sources, e.g., from *satellites*, Unmanned Aerial Vehicles (UAV), *z-value representations*, *distance representations*, *area representations*, *raster*, *vector*, *binary*, and *non-binary data*. Employed resources are High Resolution (HR) (Space) Shuttle Radar Topography Mission (SRTM) [29] data fusion [30], HR Digital Chart of the World (DCW) [31], and Global Self-consistent Hierarchical High-resolution Geography (GSHHG) [32]. SRTM was produced under the National Aeronautics and Space Administration (NASA) Making Earth System Data

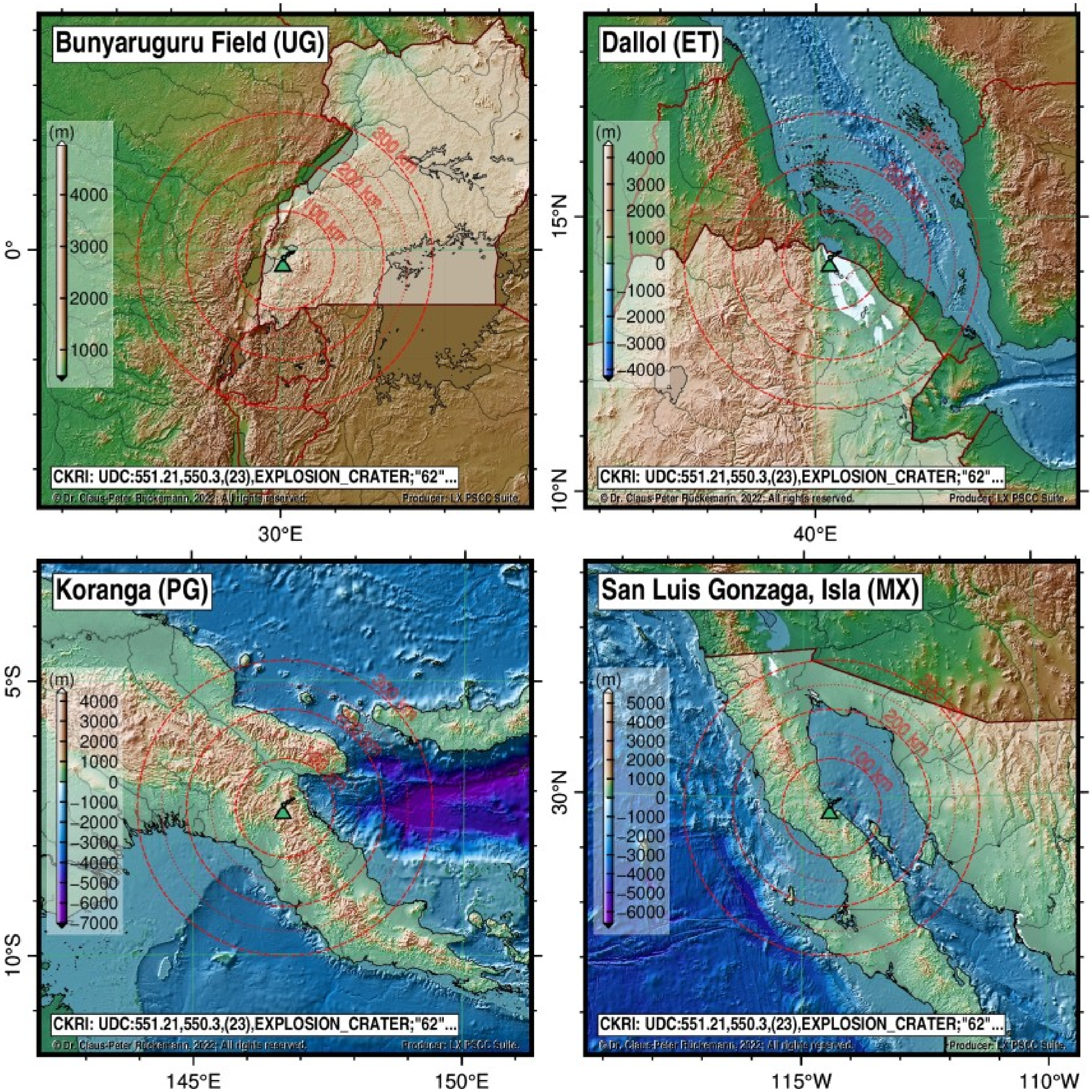

Figure 4. Resulting symbolic representation of a volcanological features group facet (explosion crater) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

Records for Use in Research Environments (MEaSUREs) program. The Land Processed Distributed Active Archive Center (LPDAAC), USA [33], operates as a partnership between the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), USA, and is a component of NASA's Earth Observing System Data and Information System (EOSDIS). Resources are released by NASA and JPL Jet Propulsion Laboratory (JPL), USA, data [34] and site [35]. SRTM15 Plus [30] is continuously updated and improved [29].

Scientific *context parametrisation of prehistoric targets* can use the overall insight from all disciplines, e.g., parametrising algorithms and creating palaeolandscapes.

Structure is an organisation of interrelated entities in a material or non-material object or system [28]. Structure is essential in logic as it carries unique information. Structure means features and facilities. There are merely higher and lower facility levels of how structures can be addressed, which result from structure levels. Structure can, for example, be addressed by logic, names, references, address labels, pointers, fuzzy methods, phonetic methods. The deployment of long-term universal structure and data standards is essential. Relevant examples of sustainable implementations are *NetCDF* [36]

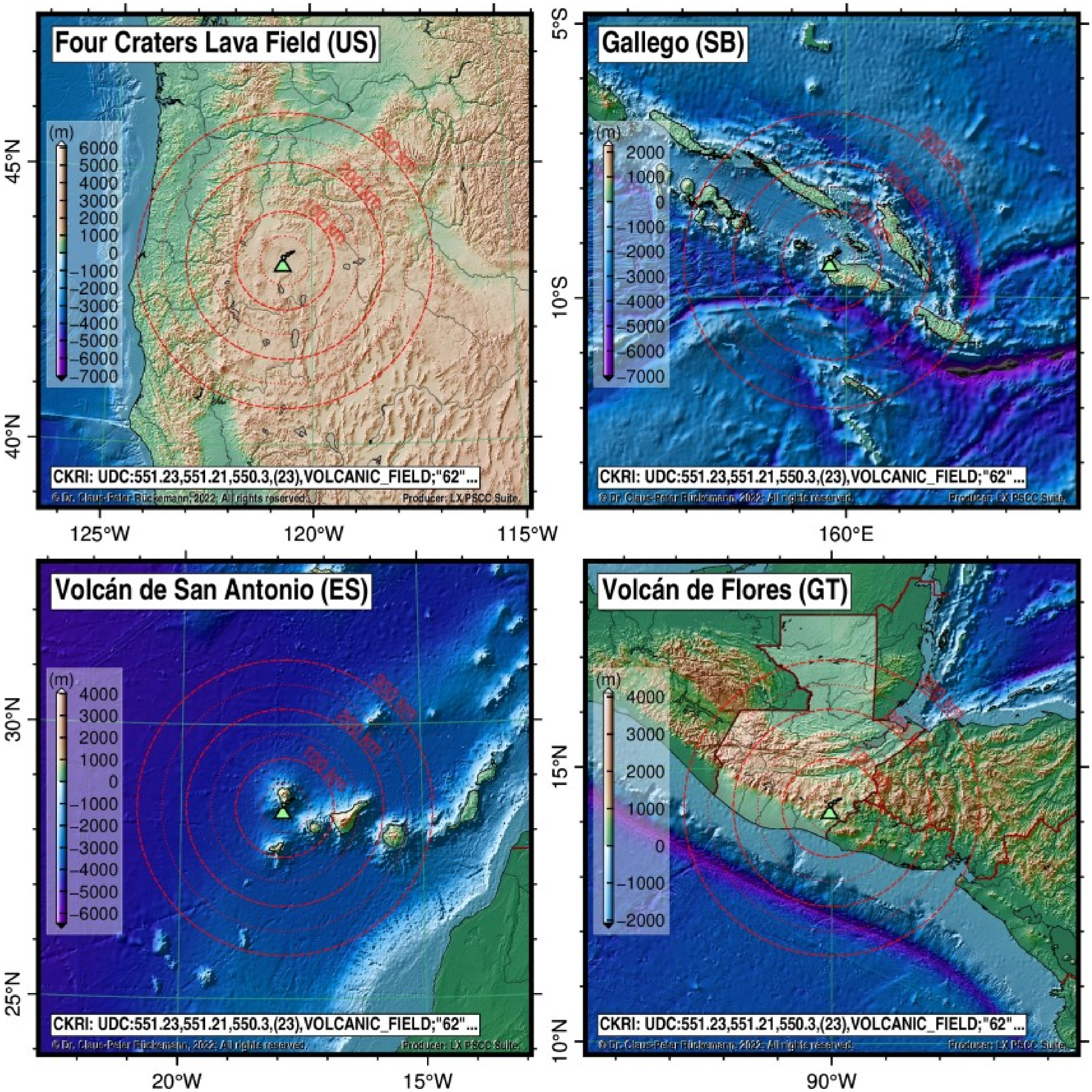

Figure 5. Resulting symbolic representation of a volcanological features group facet (volcanic field) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

based standards, including advanced features, hybrid structure integration, and parallel computing support (*PnetCDF*) and generic multi-dimensional table data, standard xyz files, universal source and text based structure and code representations.

VI. Discussion

Implementation and realisation provide a coherent conceptual contextualisation and a seamlessly coherent conceptual knowledge integration and faceting with any available knowledge resources.

The methodology and its implemented methods proved to enable sustainable, advanced contextualisation [37] and method integration [38], e.g., for prehistorical and classical archaeology and their multi-disciplinary contexts.

The practical Holocene-prehistoric inventory of volcanological features groups shows important characteristics for multi-disciplinary knowledge space, e.g.:

- Coherent conceptual knowledge integration.
- Selection and coherent integration of resources.
- Flexible criteria for knowledge integration.

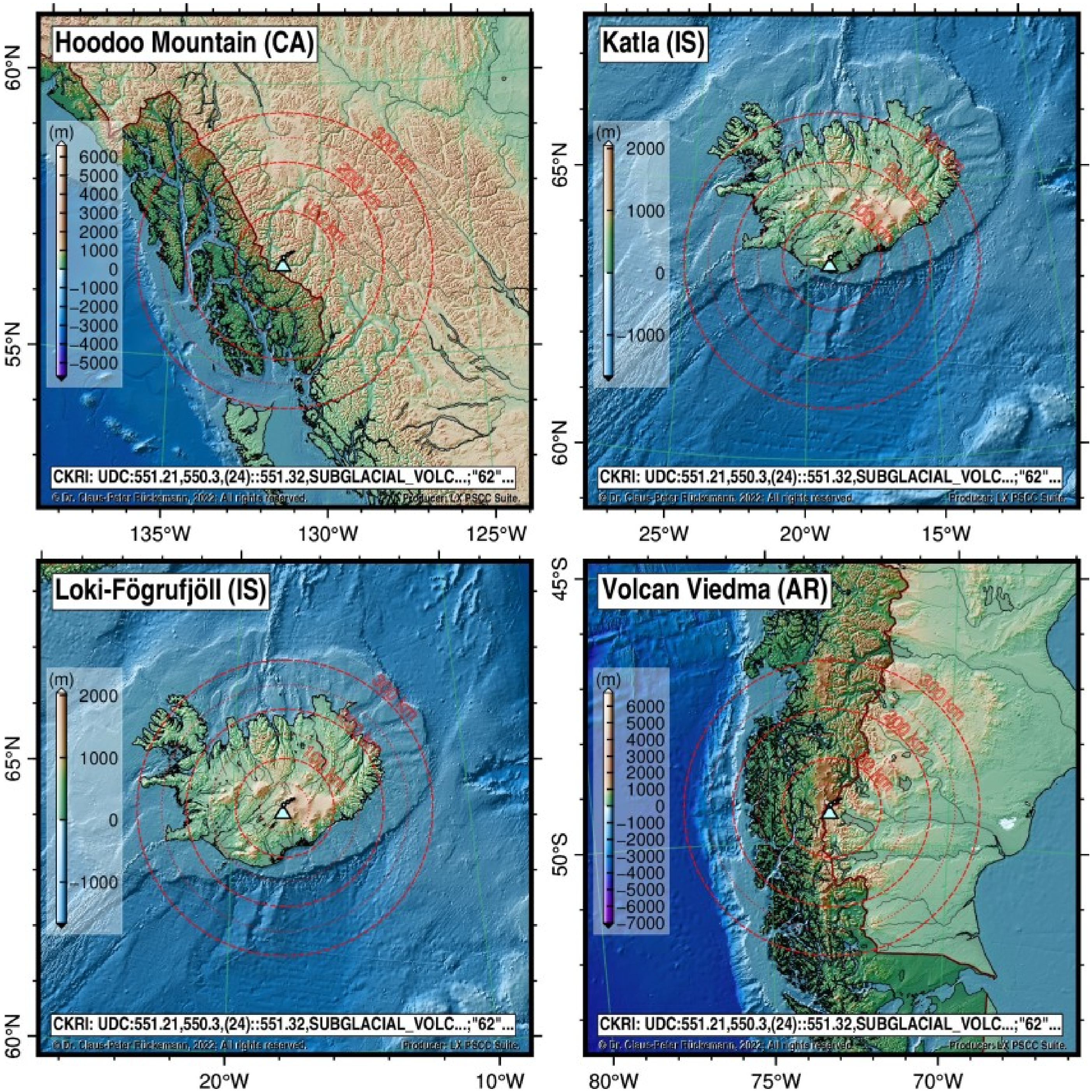

Figure 6. Resulting symbolic representation of a volcanological features group facet (subglacial volcano) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

- High level of knowledge consistency.
- High level of reproducibility for workflows and results.
- Automated and semi-automated workflow creation.
- Consequent multi-language support (e.g., UDC).
- Deployment of structural knowledge.
- Deployment of available processing and filtering.
- Spatial integration and processing.
- Georeferencing, generic components and results.

Characteristics for component space are, e.g.:

- Dynamical integration of resources and workflows.
- Arbitrary numbers of contextualisation results.
- Flexible creation of workflows and parallelisation.
- Scalable realisation, e.g., parallelisation models.

Knowledge and its complements are interrelated with possible structures and the organisation of knowledge, which contributes to the facilities, which can be parametrised and deployed, e.g., flexibility of data locality and parallelisation.

The reference implementation supports parallelisation, e.g., embarrassingly parallel procedures, e.g., via OpenMP [22] and job parallel procedures.

The CRI framework components allow efficient paralleli-

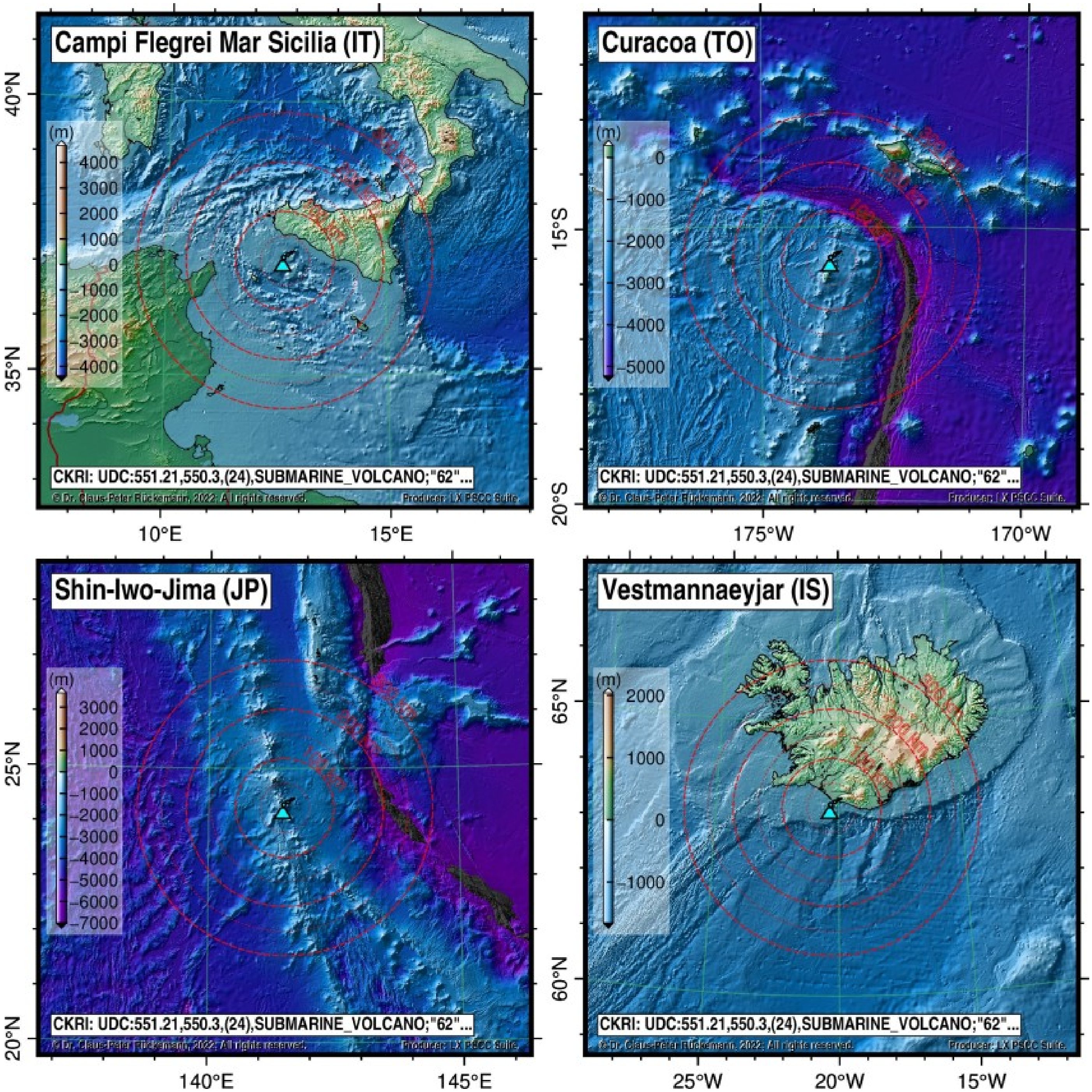

Figure 7. Resulting symbolic representation of a volcanological features group facet (submarine volcano) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

sations for any part of workflows and resources, e.g., parallel computation, processing, and generation of frames from satellite data including parallel deployment of Knowledge Resources for multi-dimensional model creation.

Each set of component integration can range from a few to millions of entities for each result group and in consequence millions of symbolic representations for integrated contexts.

In the case of the practical Holocene-prehistoric inventory of volcanological features groups we create about 500–1000 basic object entity sets per context.

The CKRI and the CRI framework enable flexible, systematical, and sustainable multi-disciplinary contextualisation from methodology to realisation, e.g.,

- semi-automated referencing,
- chorology views,
- chronology views,
- multi-disciplinary contexts,
- automated symbolic representation, e.g., graphical representation and visualisation,
- sustainable standardised components,

and a myriad of further features.

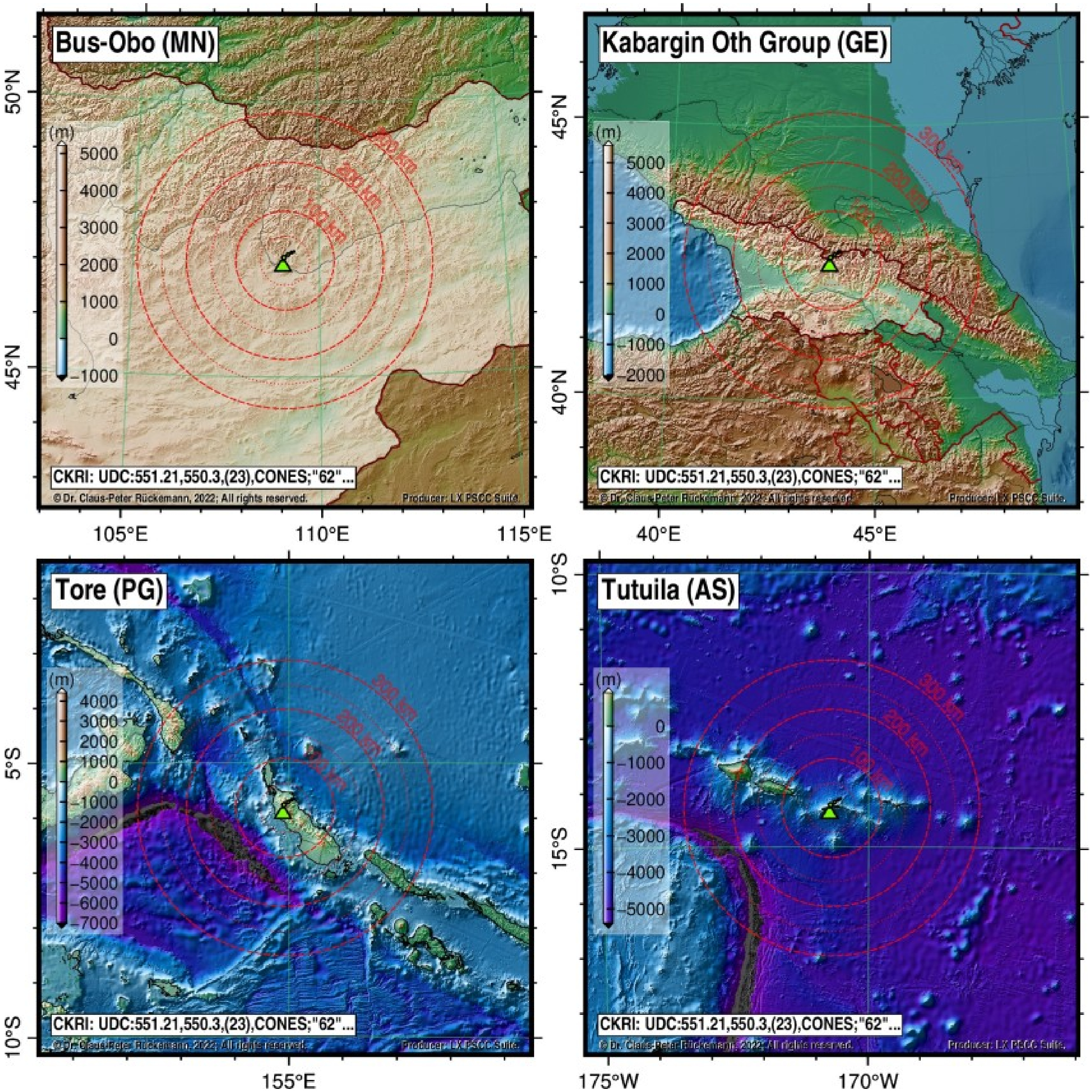

Figure 8. Resulting symbolic representation of a volcanological features group facet (cones) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

Together with the corresponding procedural component framework implementation, the CKRI will on long-term be employed in a wide range of disciplines and different ongoing projects in prehistorical and classical archaeology and multi-disciplinary contextualisation.

VII. Conclusion

Employing the methodology of coherent conceptual knowledge contextualisation for developing a coherent context integration in prehistory and archaeology proved effective, efficient, scalable, and sustainable during all long-term development and practical use.

The goal of creating a practical Holocene-prehistoric inventory of worldwide volcanological features groups facets based on the CKRI and CRI framework was successful achieved and allows further coherent contextualisation with knowledge resources, especially for the integration and contextualisation of multi-disciplinary research in prehistory, archaeology, natural sciences, and humanities.

Procedural knowledge and realisation aspects, e.g., component framework, data integration from prehistory and ar-

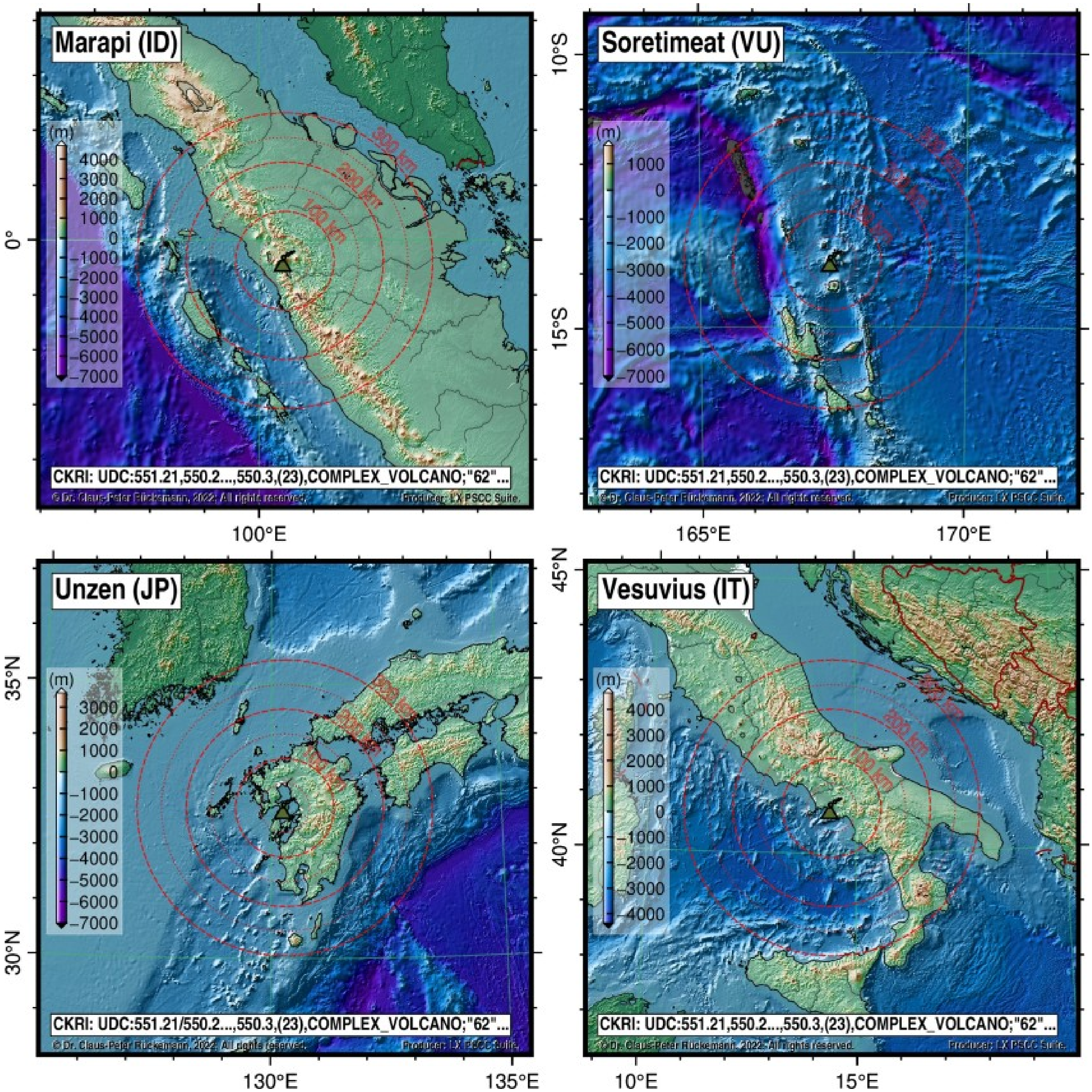

Figure 9. Resulting symbolic representation of a volcanological features group facet (complex volcano) based on coherent conceptual knowledge integration (excerpt). Generated results include CKRI references, projection of bathymetric / topographic results, and further knowledge for respective areas.

chaeology, satellite data processing, and further parallelisation development, are addressed by a separate long-term research work package [5].

The methodology enables the practical contextualisation and integration of knowledge, supporting systematical and methodological backprojections for disciplines employing their methods in interaction with future multi-dimensional and multi-disciplinary knowledge models and symbolic representations.

Future work will address the resulting and continuously further developed Holocene-prehistoric inventory of worldwide volcanological features, continuous resources development, coherent multi-disciplinary conceptual knowledge contextualisation, new advanced multi-dimensional context integration models, and integration with prehistorical and archaeological knowledge resources, e.g., with the ongoing multi-disciplinary development of PAKA [17], including further georeferencing and spatial processing.

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A Unified Air Quality Assessment Framework Based on Linear Fuzzy Space Theory

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***Abstract* - Air quality is one of the most critical issues that humankind is facing today. There are diverse types of indices measuring air pollution, which are mostly based on aggregation functions. This paper proposes a model aimed at forecasting aggregated air pollution indices, which enables modelling data uncertainties. The proposed original model consists essentially of two sub models. The first one models Air Quality Index (AQI), while the second one models concentrations of pollutants. Multi-contaminant air quality index is modelled as an aggregation of the Pollutant Standard Index (PSI) obtained via fuzzy linear transformation defined by fuzzy breakpoints. We model concentrations of pollutants by regression (XGBoost, Deep Neural Network, ADA Boost, and Histogram Gradient Boosting Regressor) using fuzzy time series of two groups of data (pollutants' concentrations and meteorological parameters). In doing so, the target variable was modeled in two ways. The first model is a set of independent classes defined by proper fuzzy membership functions, while the second one is a set of classes connected by an ordering relation. Simulation results are presented showing the model performance for each of the target variable models in terms of prediction mean absolute errors. The main result of the paper is a unified model of air quality assessment relying upon a consistent mathematical theory called Linear fuzzy space.**

Keywords - Linear fuzzy space; AQI index; aggregation operator; connected classes.

I. INTRODUCTION

This paper is an extended version of our conference paper "Linear Fuzzy Space Based Framework for Air Quality Assessment" [1] presented at the INTELLI 2022 Conference held in Venice in May 2022.

In relation to the initial work, this work introduces an improvement related to modeling the target variable. While in the original paper the target variable was modeled by independent classes described by appropriate membership functions, in this paper the target variable is modeled as a set of classes with an ordering relation.

The research presented in both the original and extended papers is motivated by the fact that in the last decade, humankind has been facing air pollution as one of the most important issues with adverse effects on human health, but also on the economy of societies. According to WHO's annual World Health Statistics report from 2016, outdoor air pollution causes approximately 4.2 million deaths per year [2]. As reported by the European Environmental Agency (EEA) in 2018, the number of deaths in Europe related to concentrations of the particles PM2.5 was about 379,000 [3]. Therefore, there is a great need for air pollution forecasting models that will express the air pollution as a simple value that is understandable for a wide audience.

Air pollution is an extremely complex spatio-temporally determined dynamic system distinctly characterized by the presence of imprecision and uncertainty. Therefore, it is not easy to give a precise air pollution forecast, which would be of great importance for public health.

To cope with uncertainty and imprecision, we use a fuzzy approach. More precisely, the one based on our previous results presented in [4] [5] [6] [7] [8], where we introduced mathematical models for basic concepts: fuzzy point, fuzzy spatial relation, fuzzy ordering, fuzzy distance, fuzzy measurement and simple geometrical fuzzy objects (line, triangle, circle). For modelling the temporal dimension of air pollution, we use a combination of time series models with techniques supporting the manipulation of imprecise and uncertain data, known under the umbrella term Fuzzy Time Series (FTS). This model enables a more adequate air pollution forecast.

Multi-contaminant Air Quality Index/Common Air Quality Index (AQI/CAQI) manages multiple effects due to the exposure to more pollutants, gives more complete information on the possible impacts of air pollutants and a direction for a more accurate, consistent, and comparable

AQI/CAQI system. Hence, we opt for multi-contaminant AQIs/CAQIs as a model of air pollution estimate.

For that purpose, the ordering relations $\leq^{RF}$ and $\leq^{LF}$ were introduced and it was proved that they agree with the definition of the fuzzy ordering with respect to the t-norm T and the equivalence E ($T-E$ ordering) from the Linear fuzzy space.

Simulations were performed for the two proposed target variable models on the same data set using the same regression models (XGBoost, Deep Neural Network, ADA Boost, and Histogram Gradient Boosting Regressor).

The obtained results showed the superiority of the model of connected classes over the model of independent classes in terms of mean square error.

The rest of the paper is organized into five sections. Section 2 presents related work, Section 3 brings theoretical foundations, while Section 4 presents the model of the proposed framework. Section 5 shows model application and simulation results for the real data set (82457 samples/16 variables/24h measurements). Finally, Section 6 summarizes the research results, identifies deficiencies, and outlines future research.

II. Related work

This section brings analysis of related work and basic underlaying preliminaries of our research.

As already said, air pollution is a complex spatio-temporally determined dynamic system characterized by the presence of imprecision and uncertainty, which makes air pollution modelling and prediction a challenging task. The research field itself is vivid, yearly generating hundreds of publications, which deal with the modelling task. There are also several recent papers that provide more-less inclusive overview of the field like [9] with specific objectives (a) to address current developments that push the boundaries of air quality research forward, (b) to highlight the emerging prominent gaps of knowledge in air quality research, and (c) to make recommendations to guide the direction for future research within the wider community. This research identifies Earth system modelling as offering considerable potential by providing a consistent framework for treating scales and processes.

One important issue of air quality modelling is the quality indicator, which is called Air Quality Index (AQI) in the USA and Common Air Quality Index (CAQI) in Europe. These two terms share the same semantics so we shall use them interchangeably through the rest of this text.

As shown in [10], a multi-contaminant model of AQI in which aggregation functions (aggregation operators) are applied to combine several numerical values into a single representative is predominant by far.

The simplest AQI model calculates a sub-index (AQI_i) for each pollutant i by the following linear interpolation formula:

$$AQI_i = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low}\ .$$

Here, C is the monitored ambient average concentration of pollutant i; C_{low} is the breakpoint lower than or equal to C; C_{high} is the breakpoint higher than or equal to C; and I_{low} and I_{high} are the sub-index values corresponding to C_{low} and C_{high}, respectively. The overall AQI is then calculated as a simple max aggregation:

$$AQI = \max_{i=1}^{m}(AQI_i).$$

There is ongoing research for new aggregation functions, which involve the influence of multiple pollutants [11] [12] [13] [14] [15] [16] [17] [18]. Among these AQIs, arithmetic pollutant aggregation integrates pollutants in a linear or nonlinear way, and weighted pollutant aggregation further assigns varied weights from different approaches. The General Air Quality Health Index ($GAQHI$) is proposed as a pollutant-aggregated, local health-based AQI paradigm suitable for representing a complex multi-contaminant situation:

$$Is = \left(\sum_{i=1}^{n}(AQI_i)^{\alpha}\right)^{\frac{1}{\alpha}},$$

where $\alpha \in [1, \infty]$.

An interesting modification of the United States Environmental Protection Agency (EPA) AQI is proposed in [11], giving a new index $RAQI$, which is the product of three terms:

$$RAQI = F_1 * F_2 * F_3$$

were

$$F_1 = \max(I_i), \qquad i = 1{,}5$$

$$F_2 = \frac{\sum_{i=1}^{5} Ave_{daily}\,(I_i)}{Ave_{annual}\cdot\left(\sum_{i=1}^{5} Ave_{daily}\,(I_i)\right)}$$

and the Shannon entropy function is introduced in the third term:

$$F_3 = \frac{Ave_{annual}\cdot Entropy_{daily}\left(\max_{i=1}^{5}(I_i)\right)}{Entropy_{daily}\left(\max_{i=1}^{5}(I_i)\right)}$$

This model strives to avoid ambiguity (indicating a less polluted air as highly polluted) and ellipticity (indicating highly polluted air as less polluted) by introducing entropy.

In addition, there are interesting approaches like in [12] that model the air pollution index via a mixture of distributions based on its structure and descriptive status as well as research doing with development of aggregate air quality index for a specific agglomeration [13] and tools used to inform the public about the status of the ambient air quality [14] in which different AQIs are analyzed to contribute to the sharing of air quality management practices and information to raise public awareness and to help policymakers to act accordingly.

There are also results that utilize fuzzy logic for modelling air quality indices, like those presented in [15] [16] [17] [18].

In the paper [15], Atacak and coauthors present the model in which the input variables are air pollutant criteria (PM10, SO2, CO, NO2, O3), and the output variable is fuzzy AQI. The fuzzification process is defined via the boundary values of the universal sets and the corresponding fuzzy sets (trapezoidal for input, and triangular for output variables). The rule base representing the relationship between input variables and output variables has 243 rules. The max-min inference strategy and centroid method are chosen for the inference and defuzzification process. The paper [16] proposed an index that, in addition to criteria air pollutants (CO, SO2, PM10, O3, NO2), includes benzene, toluene, ethylbenzene, xylene, and 1,3-butadiene due to their considerable health effects. Different weighting factors were then assigned to each pollutant according to its priority. Trapezoidal membership functions were employed for classifications and the final index consisted of 72 inference rules.

Time series is a model that is extensively used in air quality modelling. In [17], the authors present a comparative study of the results obtained from several models for air pollution index forecast, which shows that the fuzzy time series models outperformed the other models in terms of forecasting accuracy and computation time. Finally, [18] utilizes a fuzzy time series-Markov chain model for predicting the daily air pollution index.

Current air quality research relies heavily on machine learning. Another characteristic that could be attributed to them is the still partial observation of the phenomenon, with rare attempts at comprehensive modeling of this extremely complex system. With the pretension to show only a rough picture of the area and to connect it with the earlier claim, we have presented here a few characteristic papers. The first criterion for the selection of the presented papers was that they deal with air quality research, the second criterion was that they applied artificial intelligence techniques for research and, finally, the third criterion was that they were published in the course of 2022. An exception to the last criterion is the paper [19] from 2019, which we presented because it provides an overview of neural network models applied in the field, with the focus on the most frequently studied pollutants (PM10, PM2.5, nitrogen oxides, ozone). In this source, most of the work is devoted to the long-term forecasting of outdoor PM10, PM2.5, oxides of nitrogen, and ozone. Most of the identified works used meteorological and source emissions predictors almost exclusively. Furthermore, ad-hoc approaches are found to be predominantly used for deciding optimal model predictors, proper data subsets with the optimal model structure. Multilayer perceptron and ensemble-type models are predominantly implemented. The paper [20] is a review paper that is based on 128 articles published from 2000 to 2022. The review reveals that input uncertainty was predominantly addressed while less focus was given to structure, parameter, and output uncertainties. Ensemble approaches are used mostly, followed by neuro-fuzzy networks. The use of bootstrapping, Bayesian, and Monte Carlo simulation techniques, which can quantify uncertainty, was also found to be limited. Authors recommend the development and application of approaches that can both handle and quantify uncertainty surrounding the development of ANN models. The source [21] is also a review paper showing recent attempts to use deep learning techniques in air quality forecasts. There are presented deep networks, e.g., convolutional neural networks, recurrent neural networks, long short-term memory neural networks, and spatiotemporal deep networks, and their connection to the nonlinear spatiotemporal features across multiple scales of air pollution. The source presents deep learning techniques for air quality forecasts in diverse aspects, e.g., data gap filling, prediction algorithms, estimations with satellite data, and source estimations for atmospheric dispersion forecasts. The paper [22] is a focused one. This paper develops a hybrid modeling framework that combines the elastic net and multivariate relevance vector machine for interval-valued PM2.5 time series forecasting. Instead of directly modelling linear and nonlinear patterns of time series, there is introduced the multi-factor interval division approach and bivariate empirical mode decomposition algorithm into linear and nonlinear pattern modeling, respectively. The last source presented here [23] developed the LIFE Index-Air tool, where the air pollutant concentrations are predicted by Artificial Neural Networks trained using a set of air quality modeling simulations. Authors argued that the results show that this approach based on ANN, calibrated using a limited number of air quality modeling system simulations, can reproduce the concentration values competently.

Previous analysis of air quality research shows that research in the field of air quality modeling and prediction is active and diverse, with research that deals with inaccuracies and uncertainties in the data applying a fuzzy approach being very common. A significant lack of current research, in the opinion of the authors of this paper, is a consistent theoretical basis for modeling air quality as a temporally and spatially determined system with inaccuracies and uncertainties in the data (including spatial and temporal data).

Our work represents an investigation of the possibility to use the theory of Linear fuzzy space, which we are developing, as a theoretical basis for modeling air quality as a time-space system with inaccuracies and uncertainties in the data. In addition to theoretical results used in this paper, the theory of Linear fuzzy space includes models of imprecise 2D geometric objects (line, triangle, circle), models of imprecise spatial operations (spatial measurements, spatial transformations, spatial relations), and initial results proving the theory extensibility to a fuzzy finite automata model. In this way, a consistent framework is obtained that applies to modeling and simulation of air quality systems, including urban pollution where the space geometry plays an important role.

III. PRELIMINARIES

The theoretical foundations of our model are based on Linear fuzzy space theory, multi-contaminant fuzzy AQIs, fuzzy time series, and Machine Learning (ML)-based classification.

This section presents in brief basic underlaying preliminaries of our research, Linear fuzzy space, fuzzy aggregation operators and fuzzy time series.

A. Linear fuzzy space

In this subsection, we present the fundamental concepts of the Linear fuzzy space theory: fuzzy point, linear fuzzy space, fuzzy space ordering, fuzzy linear combination, and fuzzy space metrics, as defined in [4, 5, 6, 7, 8].

Definition 1 *Fuzzy point* $P \in R^2$, denoted by $\tilde{P}$ is defined by its membership function $\mu_{\tilde{P}} \in \mathcal{F}^2$**,** where the set $\mathcal{F}^2$ contains all membership functions $u: R^2 \to [0,1]$ satisfying the following conditions:

i) $(\forall u \in \mathcal{F}^2)(\exists_1 P \in R^2)\, u(P) = 1$,

ii) $(\forall X_1, X_2 \in R^2)(\lambda \in [0,1])\, u(\lambda X_1 + (1-\lambda)X_2) \geq min\big(u(X_1), u(X_2)\big)$,

iii) function u is upper semi-continuous,

iv) $[u]^\alpha = \{X | X \in R^2, u(X) \geq \alpha\}$ α-cut of function u is convex.

Here, a point from R^2 with a membership function $\mu_{\tilde{P}}(P) = 1$, is denoted by P (P is the core of the fuzzy point $\tilde{P}$), the membership function of point $\tilde{P}$ is denoted by $\mu_{\tilde{P}}$, while $[P]^\alpha$ stands for the α-cut (a set from R^2) of the fuzzy point.

Figure 1 shows geometrical illustration of a fuzzy point membership function $\mu(X)$ and its α-cut.

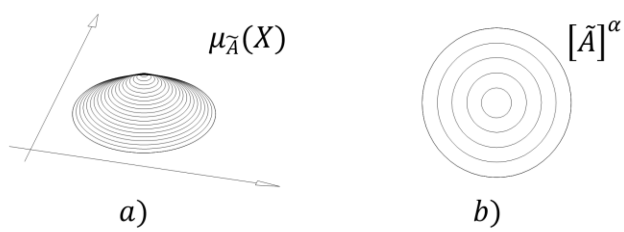

Figure 1. Geometrical illustration of a) a fuzzy point membership function and b) its α-cuts

Definition 2 R^2 *Linear fuzzy space* is the set $\mathcal{H}^2 \subset \mathcal{F}^2$ of all functions, which, in addition to the properties given in Definition 1, are:

i) Symmetric with respect to the core $S \in R^2$

$$(\mu(S) = 1), \mu(V) = \mu(M) \wedge \mu(M) \neq 0 \Rightarrow$$
$$d(S,V) = d(S,M)$$

where $d(S,M)$ is the distance in R^2.

ii) Inverse-linearly decreasing regarding points' distance from the core, i.e.:

$$\text{If } r \neq 0: \quad \mu_{\tilde{S}}(V) = \max\left(0, 1 - \frac{d(S,V)}{|r_S|}\right),$$

$$\text{If } r = 0: \quad \mu_{\tilde{S}}(V) = \begin{cases} 1 & if \;\; S = V \\ 0 & if \;\; S \neq V \end{cases},$$

where $d(S,V)$ is the distance between point V and the core S ($V, S \in R^2$) and $r \in R$ is a constant.

The elements of that space are represented as ordered pairs $\tilde{S} = (S, r_S)$ where $S \in R^2$ is the core of $\tilde{S}$, and $r_S \in R$ is the distance from the core for which the function value becomes 0.

Definition 3. A t-norm is a function $T: [0,1] \times [0,1] \to [0,1]$ that satisfies the following properties:

i) Commutativity: $T(a,b) = T(b,a)$

ii) Monotonicity: $T(a,b) \leq T(c,d)$ if $a \leq c$ and $b \leq d$

iii) Associativity: $T(a, T(b,c)) = T(T(a,b), c)$

iv) The number 1 acts as identity element: $T(a,1) = a$

Definition 4. Let X be a nonempty set and function T be a t-norm. Fuzzy relation $E: X \times X \to [0,1]$ is called *fuzzy equivalence relation* (T*-equivalence*) with respect to t-norm T if the following axioms for $x, y, z \in X$ hold:

i) Reflexivity $E(x,x) = 1$

ii) Symmetry $E(x,y) = E(y,x)$

iii) T-Transitivity $T(E(x,y), E(y,z)) \leq E(x,z)$

Definition 5. Let $E: X \times X \to [0,1]$ be a T*-equivalence*. Fuzzy relation $L: X \times X \to [0,1]$ is called *fuzzy ordering* with respect to norm T and equivalence E ($T - E$ *ordering*) if for any $x, y, z \in X$ the following hold:

i) E- Reflexivity $E(x,y) \leq L(x,y)$

ii) T-E Anti-symmetry $T\big(L(x,y), L(y,x)\big) \leq E(x,y)$

iii) T- Transitivity $T\big(L(x,y), L(y,z)\big) \leq L(x,z)$

Definition 6 Let $\mathcal{H}^2$ be a linear fuzzy space. Then, a function $f: \mathcal{H}^2 \times \mathcal{H}^2 \times [0,1] \to \mathcal{H}^2$ called a *linear combination* of the fuzzy points $\tilde{A}, \tilde{B} \in \mathcal{H}^2$ is given by:

$$f\big(\tilde{A}, \tilde{B}, u\big) = \tilde{A} + u \cdot \big(\tilde{B} - \tilde{A}\big),$$

where $u \in [0,1]$, the operator $+$ is the sum of fuzzy points, and the operator $\cdot$ is the scalar multiplication of the fuzzy point.

Note: The thesis [4] defines operations sum of fuzzy points ($+$) and scalar multiplication of the fuzzy point ($\cdot$) and proves that an ordered quadruple ($\mathcal{H}^2$, $+$, R^2, $\cdot$) is a vector space.

Figure 2 is a geometrical illustration of the linear combination of the fuzzy points $\tilde{A}, \tilde{B} \in \mathcal{H}^2$.

Measurement in space, especially the distance between plane geometry objects, is defined as a generalization of the concept of physical distance.

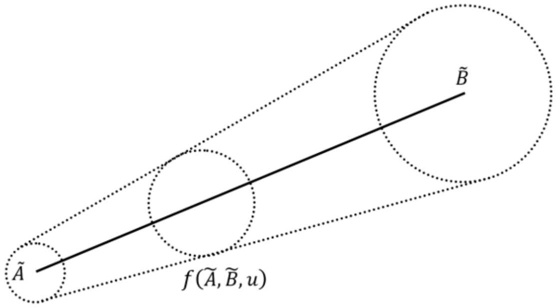

Figure 2. Geometrical ilustration of a linear combination of the fuzzy points $\tilde{A}, \tilde{B} \in \mathcal{H}^2$

Definition 7. Let $\mathcal{H}^2$ be a linear fuzzy space and $\tilde{d}: \mathcal{H}^2 \times \mathcal{H}^2 \to \mathcal{H}^+$, L, $\mathsf{R}: [0,1] \times [0,1] \to [0,1]$ be symmetric, associative, and non-decreasing for both arguments, and $\mathsf{L}(0,0) = 0$, $\mathsf{R}(1,1) = 1$. The ordered quadruple $(\mathcal{H}^2, \tilde{d}, \mathsf{L}, \mathsf{R})$ is called fuzzy metric space and the function $\tilde{d}$ is a *fuzzy metric*, if and only if the following conditions hold:

i) $\tilde{d}(\tilde{X}, \tilde{Y}) = \tilde{0} \Leftrightarrow [\tilde{X}]^1 = [\tilde{Y}]^1$

ii) $\tilde{d}(\tilde{X}, \tilde{Y}) = \tilde{d}(\tilde{Y}, \tilde{X}), \ \forall \tilde{X}, \tilde{Y} \in \mathcal{H}^2$

iii) $\forall \tilde{X}, \tilde{Y} \in \mathcal{H}^2$:

if $s \leq \lambda_1(x,z) \wedge t \leq \lambda_1(z,y) \wedge s + t \leq \lambda_1(x,y)$

$$\tilde{d}(\tilde{X}, \tilde{Y})(s+t) \geq \mathsf{L}\big(d(x,z)(s), d(z,y)(t)\big)$$

if $s \geq \lambda_1(x,z) \wedge t \geq \lambda_1(z,y) \wedge s + t \geq \lambda_1(x,y)$

$$\tilde{d}(\tilde{X}, \tilde{Y})(s+t) \leq \mathsf{R}\big(d(x,z)(s), d(z,y)(t)\big)$$

The α-cut of a fuzzy number $\tilde{d}(x,y)$ is given by

$$\left[\tilde{d}(\tilde{X}, \tilde{Y})\right]^\alpha = [\lambda_\alpha(x,y), \rho_\alpha(x,y)] \ (x, y \in R^+, 0 < \alpha \leq 1).$$

The fuzzy zero, $\tilde{0}$ is a non-negative fuzzy number with $[\tilde{0}]^1 = 0$.

B. *Fuzzy aggregation operators*

An aggregation operator has natural properties such as monotonicity and boundary conditions. In practice, the data is usually normalized, so the definition of aggregation becomes:

Definition 8. An aggregation function (operator) is a function $A^{(n)}: [0,1]^n \to [0,1]$ that satisfies the following conditions:

1. is nondecreasing (in each variable)
2. $A^{(n)}(0, \ldots, 0) = 0$ and $A^{(n)}(1, \ldots, 1) = 1$.

Aggregation applies to various fields and takes diverse forms, from the simple to quite sophisticated and complex ones, modelling the interaction between criteria, which are managed by monotone set functions and corresponding integrals [24] [25] [26] [27]. In our research, a fuzzy aggregation operator is the basic instrument for multi-contaminant AQI/CAQI modelling.

C. *Fuzzy time series*

Most of the real-world tasks that utilize time series rely on multivariate time series models [28] [29] [30] [31]. The common multivariate time series model is [28]:

Let $Z_t = [Z_{1,t}, Z_{2,t}, \ldots, Z_{m,t}]'$ be an m -dimensional jointly stationary real-valued vector process such that $E(Z_{i,t}) = \mu_i$ is a constant for each $i = 1,2, \ldots, m$ and the cross-covariances between $Z_{i,t}$ and $Z_{j,s}$ for all $i = 1,2, \ldots, m$ and $j = 1,2, \ldots, m$ are functions only of the time difference $(s - t)$.

On the other hand, the original definition of the univariate first fuzzy time series model is [31]:

Definition 9. Let $Y(t)(t = \ldots, 0,1,2, \ldots)$, a subset of R^1 be the universe of discourse on which fuzzy sets $f_i(t)(i = 1,2, \ldots)$ are defined and $F(t)$ is the collection of $f_i(t)(i = 1,2, \ldots)$. Then, $F(t)$ is called a fuzzy time series on $Y(t)(t = \ldots, 0,1,2, \ldots)$.

Our time series model is a combination of the previous two where we apply the same common multivariate model, which is modified to support imprecise values. In our model, we simply replace a crisp point with a linear fuzzy space point [4]:

Definition 10. Let $Y(t)(t = \ldots, 0, 1, 2, \ldots)$, a subset of R^1 be the universe of discourse. Let $\mathcal{H}^l$ $(l = 1,2)$ be a linear fuzzy space. Furthermore, let $f_i(t)(i = 1,2, \ldots)$ be fuzzy sets defined as points on a linear fuzzy space over the given universe of discourse, and $\tilde{F}_j(t)(j = 1,2, \ldots m)$ be collections of these fuzzy points. Then, $\tilde{F}_t = [\tilde{F}_{1,t}, \tilde{F}_{2,t}, \ldots, \tilde{F}_{m,t}]'$ is called a linear fuzzy space based fuzzy time series on $Y(t)(t = \ldots, 0, 1, 2, \ldots)$.

This definition enables all features of linear fuzzy space to be used. For example, a process vector can be of a mixed type (some components can be crisp, some can be fuzzy) whilst spatial relations defined on the linear fuzzy space hold.

IV. Fuzzy model of Air pollution indices prediction

In this example, we show how the linear fuzzy space is used for time series-based forecasting. Fuzzy time series defined by the linear fuzzy space, as described in subsection C of Section III, are used to model air quality forecast.

A. *Data model*

The data model used in this paper consists of temporal georeferenced samples. Each sample is a time series covering the earlier 24h in 1h sample rate (total 385 real values). Each time series corresponds to one variable. Variables are divided into two groups: six common air pollutants known as "criteria air pollutants" [32], and ten meteorological parameters, the Global Data Assimilation System (GDAS) [33] shown in Table I and Table II, respectively.

TABLE I. AIR POLLUTANTS PARAMETERS

ID	Description	Unit
PM10	Suspended particles smaller than 10 μm	μg/m^3
PM25	Suspended particles smaller than 2.5 μm	μg/m^3
SO2	Sulphur dioxide	ppb
CO	Carbon Monoxide	ppm
NO2	Nitrogen Dioxide	ppb
O3	Ground-level Ozone	ppm

TABLE II. GDAS PARAMETERS

ID	Description	Unit
PRSS	Pressure at Earth surface	hPa
TPP6	Accumulated precipitation (6 h accumulate.)	m
RH2M	Relative Humidity at 2m AGL	%
TO2M	Temperature at 2m AGL	K
TCLD	Total cloud cover (3- or 6-h average)	%
U10M	U-component of wind at 10 m AGL	m/s
V10M	V-component of wind at 10 m AGL	m/s
TMPS	Temperature at surface	K
PBLH	Planetary boundary layer height	m
irradiance	Irradiance/solar power	W/m2

B. Linear Fuzzy Space-based air pollution index

Since air pollutants are measured in different physical units and scales, the first step is to transform them into a common domain (0-500). This transformation is usually defined by breakpoint tables and the resulting values are called Pollutant Standard Index (PSI). Instead of using discrete functions, we propose a fuzzy linear transformation defined by fuzzy breakpoints (Figure 3).

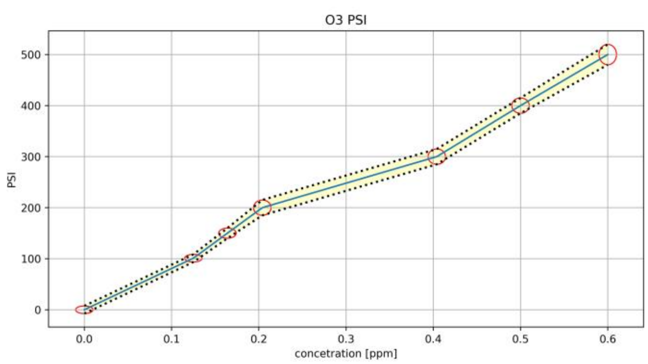

Figure 3. Fuzzy linear transformation for Ground-level Ozone (O3)

A fuzzy linear transformation is defined by an ordered list of 2D Fuzzy points $\tilde{P} = (\tilde{X}, \tilde{Y})$. Each 2D fuzzy point consists of two components $\tilde{X} = (X, r_x)$ and $\tilde{Y} = (Y, r_Y)$, which are 1D fuzzy points.

Then, Fuzzy PSI (FPSI) is defined as:

$$\widetilde{FPSI_\iota} = \widetilde{l\iota nterp}\left(C, \left[\widetilde{P_0}, \dots \widetilde{P_n}\right]\right) = (\,FPSI_i, r_{FPSI})\,,$$

$$FPSI_i = \frac{Y_{high} - Y_{low}}{X_{high} - X_{low}}(C - X_{low}) + Y_{low}$$

$$r_{PSI} = \frac{r_{Yhigh} - r_{Ylow}}{r_{Xhigh} - r_{Xlow}}(C - X_{low}) + r_{Ylow}$$

where $\widetilde{l\iota nterp}$ is a fuzzy linear transformation from concertation fuzzy space into index fuzzy space. Fuzzy points $\widetilde{P_{h\iota gh}}$ and $\widetilde{P_{low}}$ are fuzzy points whose roots of $\tilde{X}$ components are nearest to the concertation C.

$FPSI$ can be further represented by a linguistic variable, or it can be used directly in the aggregation process.

A single fuzzy value $FAQI$ is obtained by applying some fuzzy aggregation operator (aggreg) to all (n) components $FPSI$ indices:

$$FAQI = aggreg(FPSI_i), i = 1, n$$

To simplify the decision-making process and/or facilitate general understanding, a fuzzy linguistic variable defined by corresponding fuzzy sets can be easily introduced in such a model.

C. Prediction model

In our model, we opt for multivariate regression to forecast $FAQI$. However, other classification methods can easily be incorporated in the proposed model.

A prediction model in which the target variable consists of unordered classes is shown in Figure 4.

The shortcoming of this approach is that the individual membership functions, that is, the fuzzy classes, are viewed as if they were independent variables, i.e., the fact that the **Very low** and **Low** classes are "closer" than the **Very Low** and **Very High** classes is not considered.

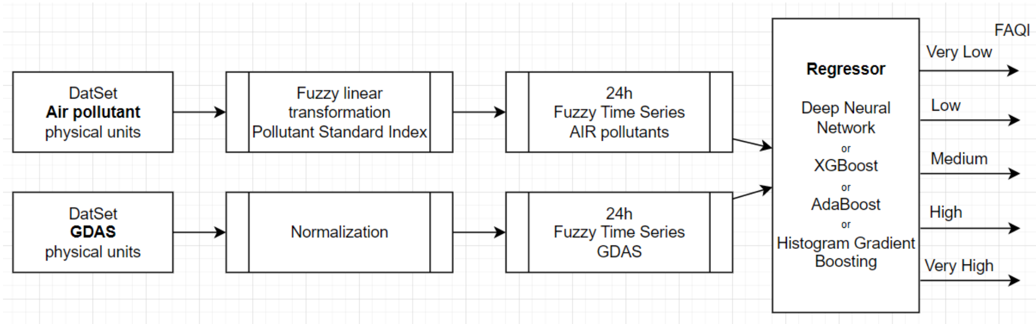

Figure 4. Prediction model with target variable modeled by unordered classes

To address this problem, this paper used the fact that classes can be arranged by the ordering relation:

Very Low ≤ Low ≤ Medium ≤ Hight ≤Very High
$$(\ \tilde{\mathbf{0}} \le \tilde{\mathbf{1}} \le \tilde{\mathbf{2}} \le \tilde{\mathbf{3}} \le \tilde{\mathbf{4}}\ )$$

If we represent the **Very Low** class with the fuzzy number $\tilde{0}$ and the **Very High** class with the fuzzy number $\tilde{4}$, then we can use the analogy with integers and real numbers, so the ordering could be like an ordering among integer numbers, and the extension of a strict class membership could be a Type 2 fuzzy membership over discourse R. Then, for example, the number 1.2 stands for a partial belonging to classes 1 and 2, which simultaneously reflects the arrangement of classes. This also expresses in a simpler way the fact:

$$F_j(AQI) = 0 \rightarrow F_i(AQI) = 0, \forall i, i > j$$

To implement this idea, we have introduced the notion of fuzzy relations $\le^{RF}$ and $\le^{LF}$.

Definition 11. Let $\mathcal{H}$ be a linear fuzzy space defined on R^1. Fuzzy relations $\le^{RF}$ and $\le^{LF}$ on the set $\mathcal{H}$ are defined by the following membership functions:

$$\mu(\tilde{A} \le^{RF} \tilde{B}) = \begin{cases} 1 & if\ A > B \\ \dfrac{B-A}{r_B - r_A} & if\ A \le B \wedge A - r_A > B - r_B \\ 0 & if\ A \le B \wedge A - r_A \le B - r_B \end{cases}$$

$$\mu(\tilde{A} \le^{LF} \tilde{B}) = \begin{cases} 1 & if\ A < B \\ \dfrac{B-A}{r_B - r_A} & if\ A \le B \wedge A - r_A > B - r_B \\ 0 & if\ A \le B \wedge A - r_A \le B - r_B \end{cases}$$

where $\tilde{A} = (A, r_A)$ and $B = (\tilde{B}, r_B)$ are fuzzy points from $\mathcal{H}$, A is the core of the point $\tilde{A}$, r_A is the parameter determining the membership function of the point $\tilde{A}$, B is the core of the point $\tilde{B}$, and r_B is the parameter determining the membership function of the point $\tilde{B}$.

Also, we have formulated the following two theorems and proved the first one (the proof of the second is analogue to the first).

Theorem 1. Let T_M − equivalence $E: \mathcal{H} \times \mathcal{H} \rightarrow [0,1]$ is given by

$$E(\tilde{A}, \tilde{B}) = \begin{cases} 1 & if\ A = B\ \wedge\ r_A = r_B \\ 0 & otherwise \end{cases}$$

and a minimum T_M − norm $(T_M(a,b) = min(a,b))$. Then the fuzzy relation $\le^{RF}$ is an ordering compliant with Definition 4.

Proof.

The following notation will be used in the proof. With A, B, C we shall denote the cores of the fuzzy points $\tilde{A}$, $\tilde{B}$, $\tilde{C}$ and with r_A, r_B, r_C corresponding maximal distances from the cores for which the membership functions are note zeroes.

What we have to prove here is that the relation $\le^{RF}$ has the following properties:

(i) E Reflexivity $\quad E(\tilde{A}, \tilde{B}) \le \mu(\tilde{A} \le^{RF} \tilde{B})$

(ii) T_M E Anti-symmetry
$$T_M\left(\mu(\tilde{A} \le^{RF} \tilde{B}), \mu(\tilde{B} \le^{RF} \tilde{A})\right) \le E(\tilde{A}, \tilde{B})$$

(iii) T_M Transitivity
$$T_M\left(\mu(\tilde{A} \le^{RF} \tilde{B}), \mu(\tilde{B} \le^{RF} \tilde{C})\right) \le \mu(\tilde{A} \le^{RF} \tilde{C})$$

***E*-Reflexivity**

If $E(\tilde{A}, \tilde{B}) = 0$, the proof is trivial. If not, from $E(\tilde{A}, \tilde{B}) = 1$, follows $A = B\ \wedge r_A = r_B$ having the consequence $\mu(\tilde{A} \le^{RF} \tilde{B}) = 1 \Rightarrow 1 \le 1$.

T_M E-Anti-symmetry

The proof is trivial for $E(\tilde{A}, \tilde{B}) = 1$.

If $E(\tilde{A}, \tilde{B}) = 0$, it should be proved that $\mu(\tilde{A} \le^{RF} \tilde{B}) = 0 \vee \mu(\tilde{B} \le^{RF} \tilde{A}) = 0$ is true.

Suppose that $\mu(\tilde{A} \leq^{RF} \tilde{B}) \neq 0 \vee \mu(\tilde{B} \leq^{RF} \tilde{A}) \neq 0$ is true. By substituting $\mu(\tilde{A} \leq^{RF} \tilde{B}) = a$ and $\mu(\tilde{B} \leq^{RF} \tilde{A}) = b$ we distinguish four cases.

1) $\boldsymbol{a = 1 \wedge b = 1}$**:**

$(A \leq B \wedge A + r_A \leq B + r_B) \wedge (B \leq A \wedge B + r_B \leq A + r_A)$ implies $A = B \wedge r_A = r_B \Rightarrow E(\tilde{A}, \tilde{B}) = 1$, which is not possible due to the assumption that $E(\tilde{A}, \tilde{B}) = 0$.

2) $\boldsymbol{a = 1 \wedge b < 1}$**:**

$(A \leq B \wedge A + r_A \leq B + r_B) \wedge (B \leq A \wedge B + r_B \leq A + r_A)$ implies $A = B \wedge r_A \leq r_B \wedge r_B > r_B$, which is not possible.

3) $\boldsymbol{a < 1 \wedge b = 1}$: Analogous to the proof of case 2).

4) $\boldsymbol{a < 1 \wedge b < 1}$**:**

$(A \leq B \wedge A + r_A > B + r_B) \wedge (B \leq A \wedge B + r_B > A + r_A)$ implies $A = B \wedge r_A > r_B \wedge r_B < r_A$, which is not possible.

T_M Transitivity

It should be proven that, for each $\tilde{A}, \tilde{B}, \tilde{C}$ from $\mathcal{H}$ defined over R^1, $min\left(\mu(\tilde{A} \leq^{RF} \tilde{B}), \mu(\tilde{B} \leq^{RF} \tilde{C})\right) \leq \mu(\tilde{A} \leq^{RF} \tilde{C})$ holds. With adopted notation, we can distinguish two cases:

1) $A > B \vee B > C$, and
2) $A \leq B \wedge B \leq C$.

For $A > B \vee B > C$ the proof is trivial because $\mu(\tilde{A} \leq^{RF} \tilde{B}) = 0$ or $\mu(\tilde{B} \leq^{RF} \tilde{C}) = 0$.

For $A \leq B \wedge B \leq C$ we distinguish two cases:

1) $A + r_A \leq C + r_C$ and
2) $A + r_A > C + r_C$.

1) The proof is trivial because of $\mu(\tilde{A} \leq^{RF} \tilde{C}) = 1$.

2) Let $\mu(\tilde{A} \leq^{RF} \tilde{C}) = \frac{C-A}{r_C - r_A} = a < 1$.

Then, the inequality $min\left(\mu(\tilde{A} \leq^{RF} \tilde{B}), \mu(\tilde{B} \leq^{RF} \tilde{C})\right) \leq a$ is true if $\mu(\tilde{A} \leq^{RF} \tilde{B}) \leq a$ is true or $\mu(\tilde{B} \leq^{RF} \tilde{C}) \leq a$ is true and, again, three cases emerge:

(i) $A + r_A \leq B + r_B$;

(ii) $A + r_A > B + r_B \geq C + r_C$;

(iii) $B + r_{\boldsymbol{B}} < C + r_C$.

For the case (i) $\mu(\tilde{A} \leq^{RF} \tilde{B}) = 1$, and for the case (iii) $\mu(\tilde{B} \leq^{RF} \tilde{C}) = 1$ the consequence of the previous statements are the following three cases:

(i) $1 \leq a \vee \frac{C-B}{r_B - r_C} \leq a$;

(ii) $\frac{B-A}{r_A - r_B} \leq a \vee \frac{C-B}{r_B - r_C} \leq a$;

(iii) $\frac{B-A}{r_A - r_B} \leq a \vee 1 \leq a$.

Let's continue with contradiction and suppose the opposite:

(i) $1 > a \vee \frac{C-B}{r_B - r_C} > a$;

(ii) $\frac{B-A}{r_A - r_B} > a \vee \frac{C-B}{r_B - r_C} > a$;

(iii) $\frac{B-A}{r_A - r_B} > a \vee 1 > a$.

Then for (i) holds that $\frac{B-A}{r_A - r_B} \geq 1 > a \wedge \frac{C-B}{r_B - r_C} > a$, while for (iii) holds that $\frac{B-A}{r_A - r_B} > a \wedge \frac{C-B}{r_B - r_C} \geq 1 > a$.

We can represent the cases (i), (ii), and (iii) as

$\frac{B-A}{r_A - r_B} > a \wedge \frac{C-B}{r_B - r_C} > a$,

This leads to the consequence

$B - A > a(r_A - r_B) \wedge (C - B) > a(r_B - r_C) \Rightarrow C - A > a(r_A - r_C)$, i.e., $\frac{C-A}{r_A - r_C} > a$.

However, this is not possible due to the assumption $\frac{C-A}{r_A - r_C} = a$ ■

Theorem 2. Let $T_M -$ equivalence $E: \mathcal{H} \times \mathcal{H} \rightarrow [0,1]$ is given by

$$E(\tilde{A}, \tilde{B}) = \begin{cases} 1 & if\ A = B\ \wedge\ r_A = r_B \\ 0 & otherwise \end{cases}$$

and a minimum $T_M -$ norm $\left(T_M(a, b) = min(a, b)\right)$. Then the fuzzy relation $\leq^{LF}$ is an ordering compliant with Definition 4.

The proof of Theorem 2 is analogous to the proof of Theorem 1.

Figure 5 shows the mapping between the unordered set of fuzzy membership functions and the new, ordered classes.

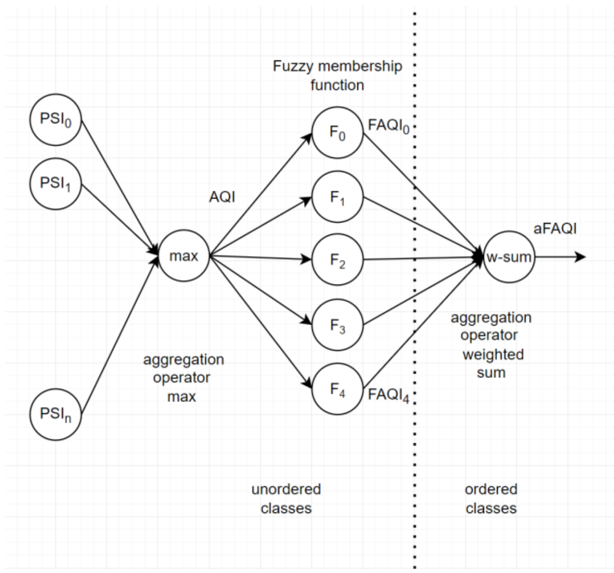

Figure 5. Modeling ordered classes

The mapping is modeled through the weighted sum aggregation operator, which is defined as

$$FAQI = \sum_{i=0}^{4} i \cdot FAQI_i(AQI)$$

where i is the integer number standing for the classes (**0** for **Very Low**, **1** for **Low**, **2** for **Medium**, **3** for **High** and **4** for **Very High**) and $FAQI_i(AQI)$ is the value of the function of the measurement sample belonging to class i .

That way we obtain the prediction model in which, instead of five output values, we have a single value that captures interactions of five independent quantities, while keeping the computational complexity same as that for unordered classes.

The resulting prediction model is shown in Figure 6.

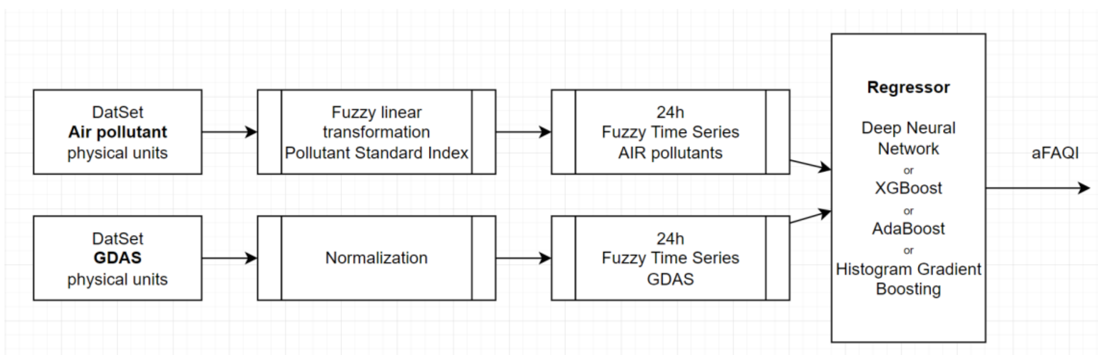

Figure 6. Prediction model with target variable modeled by ordered classes

To be able to compare the ordered and unordered case, it is necessary to calculate the total error as the mean value of the error of the example for all classes, which is calculated as:

$$Err = \frac{1}{n} \sum_{i=0}^{4} Err_i \cdot \sum_{j=0}^{n} FAQI_i(AQI_j)$$

V. MODEL APPLICATION AND SIMULATION RESULTS

To present the proposed model/methodology, we ran an experiment on a large and diverse data set. The used data set contains more than 82000 samples each with 385 real values. GDAS values are interpolated to fit five geo locations and merged with measurements of the concentration of the air pollutants.

For our experiment we used a virtual machine (VM) created as part of PARADOX HP Proliant SL250s with following components: Intel Xeon Processors E5-2670 (Sandy Bridge, 8 Core, 20M Cache, 2.6GHz), 106 nodes with total 1696 CPU cores and 32GB per node. Our VM is configured to use 8 cores and 32GB RAM on Debian GNU/Linux 10, Architecture x86-64.

All experiments were implemented using Python with Tensorflow 2.0, Pandas, XGBoost and Scikit-Learn main packages.

A. Data set

In this experiment, we used five data sets from five distinct locations in the USA, each in the same format. The sources of data are [32] (measurements of the concentration of the air pollutants) and [33] (meteorological data). Samples are indexed by temporal attribute, datetime, ranging from January 1, 2015. to December 31, 2021. All ten meteorological GDAS and six air pollutants are stored in a 24 hours' time slot with 1h sample rate (385 real values in total). Table III presents the data in more detail including sample sizes per location.

TABLE III. DATA SETS

Data set ID	site	Samples
11-001-0043	Washington, DC	27,981
13-089-0002	Near Atlanta, GA	21,468
18-097-0078	Indianapolis, IN	16,774
22-033-0009	Baton Rouge, LA	6,569
32-003-0540	Las Vegas, NV	9,665

The same source supplies data about land use (COMMERCIAL, RESIDENTIAL) and type of location (URBAN, SUBURBAN) as shown in Table IV.

TABLE IV. SITE TYPES

Data set ID	City	Land use	Location
11-001-0043	Washington, DC	COMMERCIAL	URBAN
13-089-0002	Near Atlanta, GA	RESIDENTIAL	SUBURBAN
18-097-0078	Indianapolis, IN	RESIDENTIAL	SUBURBAN
22-033-0009	Baton Rouge, LA	COMMERCIAL	URBAN
32-003-0540	Las Vegas, NV	RESIDENTIAL	URBAN

PSI calculation was done using PSI functions (Table V), which transform the physical value domain into a real value interval [0, 500].

TABLE V. PSI BREAKPOINTS

PSI	PM10 $\mu g/m^3$	SO2 ppm	CO ppm	NO2 ppm	O3 ppm
0	0	0	0	0	0
50	50	0.03	4.5	-	0.06
100	150	0.14	9	-	0.12
200	350	0.3	15	0.6	0.2
300	420	0.6	30	1.2	0.4
400	500	0.8	40	1.6	0.5
500	600	1	50	2	0.6

B. Fuzzy air quality index

In this example of framework application, the fuzzy air quality index is modelled via a simple max aggregation function applied to five $FPSI$ indices of each criteria air pollutants:

$$FAQI = max\ (FPSI_{CO}, FPSI_{PM10}, FPSI_{NO2}, FPSI_{O3}, FPSI_{SO2})$$

Finally, we introduce a fuzzy linguistic variable (*Very low*, *Low*, *Medium*, *High*, *Very high*) defined by corresponding fuzzy sets, as depicted in Figure 7.

This fuzzy linguistic variable actually corresponds to the definition of CAQI, which describes air quality through these five categories. However, individual countries apply different scales (for example, Canada has a scale with four categories, while the USA has scale with six categories).

It is obvious that in our model this index can easily be adapted to specific needs.

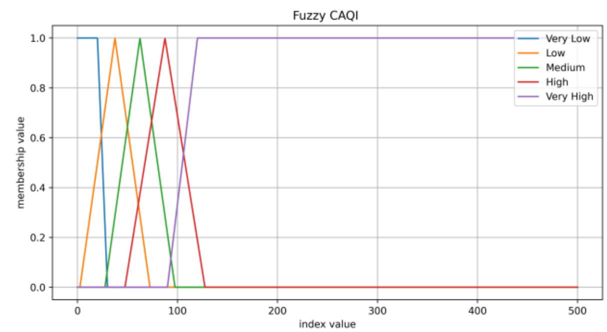

Figure 7. Fuzzy CAQI

C. ML experiments

In our experiments, we applied four multivariate regressors.

The first multivariate predictor regressor in this experiment is XGBoostRegressor with 24*10 GDAS and 24*6 air pollutant variables as input, and 5 real valued outputs, each corresponding to a single fuzzy set (FAQI_*very low* to *very high*), as depicted in Figure 3. Data set is split up into train (80%) and test (20%) subsets and trained with 1000 estimators with *max_depth* 4 and enabled early stopping method to avoid overfitting.

The second multivariate predictor regressor in this experiment is a deep neural network with 24*10 GDAS and 24*6 air pollutant variables as input, and 5 real valued outputs, each corresponding to a single fuzzy set (FAQI_*very low* to *very high*), with one hidden layer consisting of 20 Rectified Linear Units (ReLU) nodes. The activation functions in output layer are Sigmoid. The data set is split up into train (80%) and test (20%) subsets. Two dropout layers with 10% random filters are incepted between active layers to prevent overfitting.

The third multivariate predictor regressor in this experiment is ADA Boost regressor with 100 estimators, learning rate 1 and boosting algorithm SAMME.R.

The fourth multivariate predictor regressor in this experiment is Histogram gradient boosting regressor with squared error loss function, learning rate 0.1, max iterations 100, max leaf nodes 31, min samples leaf numbers 20, without regularization and max bins 255.

D. Simulation results

The mean absolute errors for FAQI prediction with unordered classes are shown in Table VI (XGBoost), Table VII (Deep Neural Network), Table VIII (ADA Boost), and Table IX (Histogram gradient boosting).

The tables show that all regressors behave similarly. Moreover, they are good in prediction for categories *Medium*, *High* and *Very high* and poor in prediction for categories *Very low* and *Low*. Having that in mind and the main purpose of the FAQI to alert of dangerous air pollution (*High* and *Very high*, possibly *Medium*), the results showed that further research was needed and justified.

TABLE VI. XGBOOST

Data set ID	Very low	Low	Medium	High	Very high
11-001-0043	0.229	0.230	0.049	0.003	0.001
13-089-0002	0.239	0.217	0.036	0.004	0.001
18-097-0078	0.213	0.213	0.065	0.006	0.001
22-033-0009	0.224	0.218	0.063	0.009	0.000
32-003-0540	0.083	0.236	0.185	0.045	0.012

TABLE VII. DEEP NEURAL NETWORK

Data set ID	Very low	Low*	Medium	High	Very high
11-001-0043	0.405	0.399	0.065	0.003	0.001
13-089-0002	0.460	0.398	0.045	0.004	0.002
18-097-0078	0.425	0.406	0.074	0.005	0.002
22-033-0009	0.426	0.392	0.056	0.008	0.001
32-003-0540	0.109	0.362	0.291	0.039	0.010

TABLE VIII. ADA BOOST REGRESSOR

Data set ID	Very low	Low*	Medium	High	Very high
11-001-0043	0.3336	0.328	0.1146	0.0195	0.0001
13-089-0002	0.3516	0.3140	0.0684	0.0095	0.0002
18-097-0078	0.339	0.3226	0.1221	0.048	0.001
22-033-0009	0.337	0.3283	0.096	0.046	0.0001
32-003-0540	0.1526	0.3282	0.2879	0.0965	0.035

TABLE IX. HISTOGRAM GRADIENT BOOSTING REGRESSOR

Data set ID	Very low	Low*	Medium	High	Very high
11-001-0043	0.2478	0.2574	0.0425	0.0031	0.001
13-089-0002	0.2608	0.2414	0.0332	0.0067	0.001
18-097-0078	0.2313	0.2492	0.0615	0.0062	0.001
22-033-0009	0.2397	0.2348	0.0549	0.0139	0.001
32-003-0540	0.083	0.2509	0.1794	0.0472	0.018

In the next step, a prediction model with ordered classes was applied. Using the same regressors, the results shown in Table X were obtained.

TABLE X. RESULTS OBTAINED WITH ORDERED CLASSES APPROACH

Data set ID	Deep neural network	XGBoost	AdaBoost	Histogram Gradient Boosting Regressor
11-001-0043	0.15353	0.1583	0.1558	0.1509
13-089-0002	0.11429	0.1209	0.1238	0.1092
18-097-0078	0.16035	0.1521	0.1517	0.1532
22-033-0009	0.15211	0.1539	0.1448	0.1460
32-003-0540	0.29561	0.3416	0.3210	0.3118

Finally, Table XI shows the comparative results obtained using two proposed models of the target variable.

TABLE XI. PERFORMANCES OF THE PREDICTION MODELS WITH UNORDERED AND ORDERED CLASSES

Data set ID	Mean absolute error	
	Unordered classes	Ordered classes
11-001-0043	0.40341	0.15353984
13-089-0002	0.45718	0.11429921
18-097-0078	0.42278	0.16035105
22-033-0009	0.42340	0.15211709
32-003-0540	0.11300	0.29561046

Simulation results for the target variable modelled as independent classes show that this model is characterized by a distinct property, which is a satisfactory performance for higher values of air quality index, and significantly worse (mean absolute errors higher for an order of magnitude) performance for lower values. In that case, the overall mean absolute prediction error was between 0.403 and 0.457 (except for the data set 32-003-0540 with mean absolute error of 0.11). This was a notable deficiency of the model calling for improvement that should ensure at least approximately equal performance for all categories.

Simulation results for the model in which the target variable is modelled as a set of ordered classes showed better performance. In this case, the overall mean absolute prediction error was between 0.114 and 0.160 (except for the data set 32-003-0540 with mean absolute error of 0.295), and the maximum error (again for the low pollution value classes) was of the same order of magnitude as for the high pollution value classes.

VI. CONCLUSION

This paper proposes a framework aimed at forecasting the aggregated air pollution index that is based on our Linear fuzzy space theory and fuzzy aggregation operators. The proposed model consists of two sub models. The first one models the concentration of pollutants, while the second one models multi-contaminant air quality index. We model the concentration of pollutants by regression using fuzzy time series of two groups of data: measured concentrations of pollutants and meteorological parameters with the target variable modeled in two ways. In the first case, the target variable consists of independent classes defined by proper membership functions, while in the second case, it is modeled by a set of classes connected by an ordering relation. The multi-contaminant air quality index is modeled as a fuzzy aggregation of PSI obtained via fuzzy linear transformation defined by fuzzy breakpoints.

Simulation results for the target variable modelled as unordered classes show that this model is characterized by a distinct property, which is a satisfactory performance for higher values of air quality index, and significantly worse (mean absolute errors higher for an order of magnitude) performance for lower values. This was a notable deficiency of the model calling for improvement that should ensure at least approximately equal performance for all categories. To improve the model performance, we model the target class as a set of ordered classes, which gave better performance in terms of mean absolute error.

However, air pollution is a result of an extremely complex and interdependent interaction among multiple factors (air pollutants, environment, time, climate conditions, etc.) additionally burdened with uncertainty and imprecision in data. This makes a single index an extremely rough approximation of the considered pollution situation.

Indeed, there is a potential for improvements in the research topics tackled in this paper, which shapes further research directions. The possible improvements could be further divided into two rough partitions.

The first, which is of fundamental kind, is about rethinking the air pollution index concept (for example, making it contextually dependent, or making it multidimensional). Recent research related to aggregation of sequence of fuzzy measures [34] and distortion functions [35] could provide for further improvement of the air pollution index modelling.

The second one is more about "technical" improvements of the model proposed in this paper: use of additional variables (like those in Table IV), training data balancing (in our experiment clearly indicated by results obtained for the data set 32-003-0540), learning shapes of membership functions from historical data, and alike. Improvements should specifically address creation of precision metrics in linear fuzzy space, enabling estimations of sensitivity of interval partitions selection in time series, aggregation models, and fuzzy sets parameters. Recent theory development (see [36], [37]) gives a method for identification of the optimal solution for convex and non-convex optimization in fuzzy approach that could help to do this.

The two partitions intersect at utilization of Artificial Intelligence (AI) methods, particularly fuzzy approach relying upon Linear fuzzy space and other stuff concerning imprecision and ambiguity management, and machine learning techniques.

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Supporting Systems Thinking Application by Data Analysis

A Case Study: An Automated Parking System

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***Abstract*— This study applies Systems Thinking (ST) and its tools to define and validate a case study in the early phase of a complex socio-technical research project. We used ST and other tools, including a stakeholder interest map, context diagram, and Customers, Actors, Transformation, Worldview, Owner, and Environment (CATWOE) analysis. These tools are the foundation of ST systemigrams, which is a top-down approach. Further, we support ST with data analysis, which is a bottom-up approach. In this context, we collected and analyzed failure data. We applied machine learning in terms of Natural Language Processing (NLP), Frequent Pattern Growth Algorithm (FBGL) for association rule mining, and the Gensim model to cluster the failure data. The case study indicates that both approaches complement each other as we apply them in an iterative and recursive manner. Data analysis supports ST, and ST guides the data analysis. Furthermore, ST implementation facilitates understanding, communication, and decision-making regarding the case study and its multiple units of analysis. Moreover, we adapt Nonaka and Takeuchi's model to articulate the tacit knowledge within the Company using Systemigrams, canvas in the form of A3s, and post-its. We adopted the Systems Engineering methodology to construct the canvas we used in the workshops and interviews.**

Keywords- Case study; Systems Thinking; systemigram; failure data; data analysis; machine learning.

I. Introduction

This paper is an extended version of the article presented at the Modern Systems Conference 2022. The conference paper aims to apply Systems Thinking (ST) to validate a case study definition in the early phase of a complex socio-technical research project, where the case is an Automated Parking System (APS) [1]. ST is a process focusing on understanding the problem and its aspects and relations among these aspects as a whole [2]. In this context, Barry Richmond, one of the pioneers of ST, mentioned that it is essential for a systems thinker to look at the tree and forest simultaneously [3]. In other words, ST focuses on synthesis by analyzing the whole system, its parts, and its dynamic behavior. Synthesis is one of the foundations of ST, emphasizing parts, things, or aspects to understand them through the context of their relationships. On the other hand, the analysis focuses on dealing with one part, thing, or aspect as a system using reductionism. Reductionism is a process of breaking down a system into its elemental part, then describing the whole as a sum of its elementary parts of the system [4].

However, the system as a whole is more significant than the sum of its parts, things, or aspects [5]. In this context, a system can be complex, a problem definition for a case study, etc. The contribution of this extended version is applying both ST and analysis in a complementary manner. ST, which is a top-down approach, guides failure data analysis. Failure data analysis, which is a bottom-up approach, supports ST. In other words, ST and data analysis support and guide each other in an iterative and recursive manner. In addition, the extended version addresses tacit knowledge articulation from the Company's key persons in terms of data and visualization using ST and Systems Engineering (SE) methodologies. The International Council on SE (INCOSE) defines SE as "*Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.*" [6]

We use systemigrams, an ST tool, for this articulation, where we use SE methodology to construct a virtual board using tools such as a canvas in the form of A3s and post-its described in section IV. This implementation enhances the understanding of the case study in breadth through ST and SE and in depth through data analysis.

This research uses a case study within a complex socio-technical project called H-SEIF 2 [7]. H-SEIF stands for “Harvesting value from big data and digitalization through the Human Systems Engineering Innovation Framework.” H-SEIF 1, the first research project, focused on developing new human-centered SE methods to cope with the rapid increase of socio-technical complexity within the systems and market needs [8]. H-SEIF 2, the following research project, focuses on digitalization, enabling data-supported early decisions and capturing value from big data. The H-SEIF 2 research project seeks to enhance the companies’ product development process through relevant industry cases. The research initiative uses an industry-as-laboratory method and includes two universities and nine companies from various fields. Defining and early validating the case study is essential to ensure the research project's success as it facilitates a Company’s active participation and sharing of all needed data. Ali et al. [9] are also one of the foundations of the H-SEIF 2. That research [9] showed the value of analyzing data to close the feedback loop to the early phase of the product development process.

The Company’s case study delivers Automated Parking Systems (APS), mainly in metropolitan cities. Metropolitan cities can benefit from Automated Parking Systems (APS) since there is a shortage of available land and a need for more parking spaces [10]. However, APSs frequently fail for two reasons: when used often and when the end-user is unfamiliar with the APS. Additionally, some mechanical issues cause the APS to malfunction [2][3]. An APS has a higher failure rate than a conventional system. Consequently, there is a requirement to raise APS reliability [13].

This research applies ST and its tools to define and validate a case study early using ST and other tools, including systemigrams. Systemigrams also aided in articulating the Company's tacit knowledge in terms of data and visualization. In addition, we used a canvas in the form of A3s and post-its for this articulation using a virtual board. We used SE methodology to construct the canvas in the form of A3s, and we used post-its in the digital workshops. This articulation is crucial to maintain the knowledge management process in the Company, which is vital for a competitive advantage and survival.

Moreover, we supported the ST application with data analysis. In this context, we collected and analyzed failure data using machine learning. We used machine learning in terms of Natural Language Processing (NLP) [14] and further association rule mining to discover patterns and co-occurrence among the failure data, as the data are mainly in a text-free format that is logged by the maintenance personnel. We used the Frequent Pattern Growth (FPG) algorithm for association rule mining. In addition, we clustered the failure data using machine learning using the Gensim model.

A. Introduction to the Company Where We Conducted the Research

The Company is a small and medium-sized enterprise that delivers APS in Scandinavia, mainly Norway and Denmark. The Company has more than 36 parking installations. The Company primarily provides semi-automated parking systems, the System-of-Interest (SOI) for this study, which we refer to as APS in the rest of the paper. The Company is transitioning to manufacturing its parts instead of getting the parts from suppliers. In this transition, the Company’s vision is to install sensors to develop a Condition-Based Maintenance (CBM) system. The Company believes that this vision will give the ability to increase the Company’s market share for the whole of Europe. In addition, the Company believes that being a first mover in this direction will allow the Company to sell the CBM as a service to other industries. Further, they see it as a build-up toward a digital twin.

The Company uses an Excel file to log the failures called failure data for each parking installation. The challenge is to investigate the value of this data. Due to the complexity of the data, it can be called big data [9]. The use of (big) data will enhance the APS’s reliability. This enhancement adapts to earlier data-driven decisions in product development and maintenance [15].

The research questions for this study are as follows:

RQ1: How can we define and validate a case study early, including its multiple units of analysis using Systems Thinking and its tools?

RQ2: How can we articulate tacit knowledge?

RQ3: How can we support Systems Thinking with data analysis?

Many authors suggest using Soft System Methodology (SSM) to develop a conceptual model. ST and its tools, mainly systemigrams, use SSM as a methodology [16]–[18]. Thus, ST implementation and its tools, primarily a systemigram, is a conceptual model.

The structure of the paper after the introduction section is as follows: (II) Background section with an informal literature review, (III) Research methodology section explaining case study research and Checkland’s Soft Systems Methodology, (IV) results and analysis section that includes: (a) articulating tacit knowledge (b) Systems Thinking implementation (c) data analysis results, (V) a thorough discussion in the relation of the research questions, and ultimately (VI) conclusion. The paper has a detailed data analysis methodology in Appendix A.

II. BACKGROUND

The background section provides informal literature, starting with defining ST and its tools, mainly the systemigram, then explaining the data, and information, ending by illustrating knowledge taxonomy and Nonaka and Takeuchi’s model of knowledge creation regarding tacit knowledge articulation. The informal literature review illustrates the two disciplines, i.e., ST and data analysis. Many authors addressed a lack of empirical research to apply the two disciplines [19][20]. This research addresses this gap by

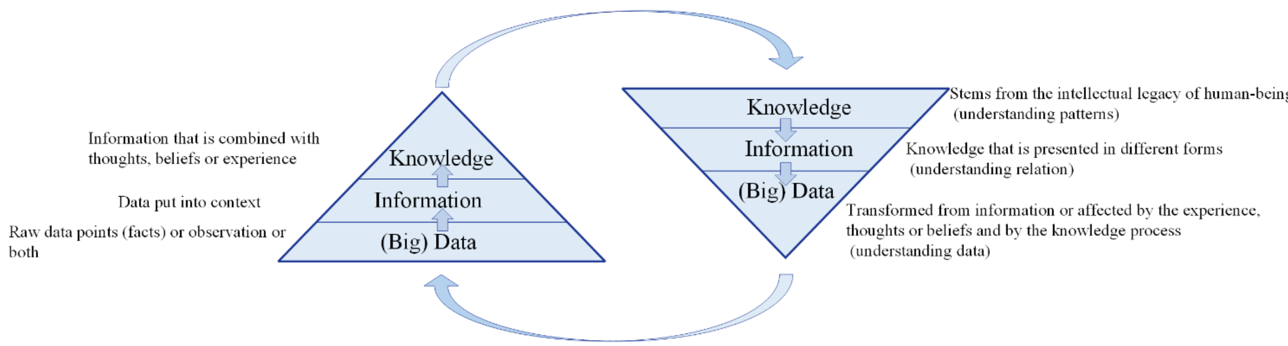

Figure 1. Data, information, and knowledge transformation and vice versa.

implementing both disciplines. In addition, we address tacit knowledge articulation in terms of data and visualization using ST and SE methodologies.

A. Systems Thinking (ST)

In 1994, Barry Richmond introduced ST as a term. He defined ST as the "*art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure*" [3]. Barry Richmond emphasized one essential attribute of a systems thinker in this context: the ability to look simultaneously at the tree and the forest. However, there are many definitions of ST. Arnold and Wade proposed an ST definition based on a literature review and ST implementation [21]. We adopted this proposed definition in this paper:

"*Systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system*".

Furthermore, Sauser et al. [2] used ST methodology and its tool, i.e., systemigram, to define a problem. The authors chose the ST methodology, as ST gives an understanding of how things affect each other as a whole. The authors visualize this understanding using a systematic diagram technique (ST's tool) called Systemigram.

1) Systemigram

A systemigram, also known as a systemic diagram, is an ST tool introduced by Boardman [22]. A systemigram is a graphical visualization using storytelling. This visual presentation consists of nodes and links. The nodes are names, and the links are the verbs between those names. A Systemigram aids in communicating through visualization a problem with its aspects and their relations. These aspects can also be related to defining a problem, solution, or both within its context. Gharajedaghi [23] claims that problems or solutions always have a specific context.

A systemigram is usually based on another ST's analysis tools, such as context diagram and Customers, Actors, Transformation, Worldview, Owner, and Environment (CATWOE) analysis [1][18]. In addition to other tools, such as a stakeholder interest map to perform a stakeholder analysis.

Implementing ST and its tool, including systemigram, needs data and data analysis support. Data and data analysis increases understanding of the several aspects within the problem or solution domain by investigating patterns among data [19]. Supporting ST and its tools with data analysis improves verification and validation [25]. In addition, ST facilitates an overview. Further, ST enhances understanding, communication, and decision-making, while data go more in-depth, and we can transform it into information through data analysis. This information can be further transformed into knowledge using ST. In other words, data and its analysis complement ST and its tools.

B. Data, information, and knowledge

Data, information, and knowledge have different meanings in knowledge management [21][22]. However, they are interconnected and related to each other. Figure 1 shows that we can transform data into information and further knowledge and vice versa.

One of the leading models that describes this transformation and differences is called the Data, Information, Knowledge, and Wisdom (DIKW) hierarchy [21][23]–[25]. Wisdom presents the future, vision, design, and implementation. Wisdom mainly means understanding the principles in order to implement them [24][25].

Data are discrete and non-significant facts, i.e., raw data points. Data can be transformed into information through, for example, analyzing the data and further visualizing these results. We derive information from the data. We may use knowledge and thoughts in the deriving process [21][24][25].

Information is a significant fact and can be further transformed into knowledge. Information is data that gets a defined meaning through an information model. The various pieces of information have relations that increase the meaning of the information further [21][24][25].

Knowledge is information that is combined with thoughts, beliefs, or experiences. In other words, knowledge is a product of data and information combined with thoughts, beliefs, or experiences. Knowledge implies understanding the patterns in which ST aids in this understanding. On the other hand, we can transform knowledge in terms of data and visualization. Knowledge stems from the intellectual legacy of human beings. Knowledge also leads to information that identifies data [21][24][25].

1) (Big) Data

There are several definitions of (big) data. Based on a literature review and articles from the industry, De Mauro et al. [31] define (big) data as follows: "Big Data is the Information asset characterized by such a High **Volume**, **Velocity,** and **Variety** to require specific Technology and Analytical Methods for its transformation into **Value**." This definition includes the " V " notion many authors have used to define (big) data. [32]–[34] used what is referred to as the "3VS" to define (big) data: Volume, Velocity, and Variety. [35]–[37] added the fourth "V" value. [38] appended the 5th V to the (big) data definition, which is Veracity.

On the other hand, the Method for an Integrated Knowledge Environment (MIKE2.0) [39] project defines (big) data emphasizing the complexity and not the size of the data: "Big Data can be very small and not all large datasets are big." Intel's definition also emphasizes the complexity aspect: "*Big data has the characteristics of being complex, unstructured, or having high volume*" [40]. Table 1 lists the most cited definitions within the literature.

TABLE I MOST CITED BIG DATA DEFINITIONS FROM THE LITERATURE

Source	Definition
(Beyer, 2012) [41]	Big data is defined using the **3Vs: Volume, Velocity, and Variety**. These characteristics require a cost-effective **information-processing model** to **improve insights** and **decision-making.**
(Dijcks, 2012) [36]	Big data is defined using **4Vs: Volume, Velocity, Variety, and Value.**
(Intel, 2012) [40]	Big data has the characteristics of being **complex, unstructured, or having a high volume.**
(Schroeck et al., 2012) [42]	Big data means a mixture of **Volume, Variety, Velocity, and Veracity**. Big data leads to a **competitive advantage** within recently **digitized** industries.
(NIST Big Data Public working Group, 2014) [43]	"Big data consist of extensive datasets, primarily in the characteristics of **volume, velocity and/or variety**, that require a scalable **architecture** for efficient storage, manipulation, and **analysis**."
(Microsoft Research, 2013) [44]	"Big data is the term increasingly used to describe the process of applying serious **computing power**—the latest in **machine learning and artificial intelligence**—to seriously massive and often highly complex sets of information."
(Boyd & Crawford, 2012)[45]	Big data is datasets with a size greater than **traditional software tools' capacity** to capture, store, manage, and **analyze**.
(Boyd & Crawford, 2012) [45]	Big is defined as a **cultural**, **technological**, and **scholarly phenomenon** that rests on the **interplay** of, **Analysis** and **Mythology**.

Based on these definitions mentioned above, including Table I, data, or big data, is a structured and unstructured data collection. In this study, we collected unstructured data from the Company; thus, MIKE2.0 and Intel's definitions apply to our case study. In other words, we adapted these two definitions to define data or (big) data in our research. However, we may expand our adaption if we can obtain or collect more structured data, i.e., in-system (sensor) data.

2) Data Sensemaking

Data sensemaking is the process of understanding the data within its context. This process occurs iteratively and recursively using data analysis and the visualization of the data analysis results. Klein et al. [46] emphasize the importance of the frame or perspective around the data as it affects the data collection, analysis, and interpretation process. Data, i.e., using data, can also affect the existing or preexisting frame regarding change or reinforcement. This effect is one of the sensemaking aspects [47].

Weick defines data sensemaking as a two-way process to fit data into a frame and frame around data. Weick emphasizes that this process must be iterative until data and frames (mental models) unite. These iterations also aid in avoiding oversimplifications [48]. Klein et al. stated that data sensemaking includes several functions, such as problem identification and detection, forming an explanation, and seeing relations or correlations [46].

C. Knowledge Taxonomy

Many authors classify knowledge into two main types: tacit and explicit knowledge [49]–[52].

Explicit knowledge is the knowledge we can codify, transfer and articulate to natural language or symbols [53]. Harry Collins calls such articulation or transformation a string. A string is a physical object with recorded patterns. For instance, a figure is a string of ink recorded on paper, and a pixel is a string of recorded patterns on a screen [44][45].

Tacit knowledge is that knowledge that is generated through a person's thoughts, beliefs, and experiences. In other words, tacit knowledge is deeply rooted in individuals (e.g., mental models, know-how, personal skills, etc.). Tacit knowledge is embedded in the action, commitment, and involvement within a particular context, which makes it challenging to articulate [44][46][47]. However, there are many ways to articulate this knowledge to some extent using SE and ST [49]. One of the models that illustrate this articulation process is Nonaka and Takeuchi's model [51].

1) Nonaka and Takeuchi's model of knowledge creation

Figure 2 visualizes Nonaka and Takeuchi's model of knowledge creation, which is generated due to social and intellectual processes [44][46][49]. This model is widely used in knowledge management for knowledge transformation and includes the following four modes:

- Socialization. This mode is about transforming tacit to tacit knowledge. This tacit knowledge is mainly generated through interactions between individuals within a particular group. Thus, learning occurs through observation, imitation, and sharing experiences.
- Combination. This mode is about transforming explicit to explicit knowledge. This explicit knowledge is the knowledge that has already been captured. We can transform it into more evident explicit knowledge, i.e., form it better through deduction or induction of previously restructured items.

- Internalization. This mode is about transforming explicit to tacit knowledge. This transformation occurs through the "learning by doing" process, for example, following a written manual.
- Externalization. This mode is about transforming tacit to explicit knowledge. This transformation contains an explanation of practices and beliefs.

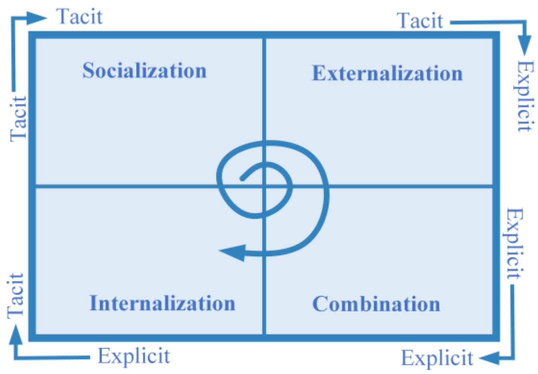

Figure 2. Nonaka and Takeuchi's model of knowledge creation.

III. Research Method

A. *Case Study Research*

In this research, we use case study research as part of industry-as-laboratory research during the research project [55]–[57]. Case study research consists of the following three steps: (1) defining the case study well, (2) selecting the design, and (3) using theory in design work [56]. This paper focuses on the first step in implementing ST. A case study often involves multiple units of analysis.

We collected primarily qualitative data. The qualitative data included direct observations, participant observations, open-ended (unstructured) interviews, and physical artifacts. The direct and participant observations resulted from the primary author being involved in a real-life context by participating in the events and meetings within the Company. We also conducted open-ended interviews separately and as part of the observation and part of the workshops, we performed with the Company.

In total, we conducted nine interviews with Company management, maintenance personnel, the head of the maintenance department, sales personnel, project leaders, and developers. In addition, we conducted three workshops with company management, maintenance personnel, and project leaders. The main author also participated in the weekly development team meetings for six months. In addition, the primary author also participated in the maintenance activities conducted by the maintenance personnel for two parking installations. The principal author also had an office in the Company and conducted several informal interviews while working from the Company's borrowed office.

Through observation, interviews, and workshops, we identified and collected stored data within the Company, also called physical artifacts. These data were downloaded by the Company's employees and provided to the primary author of this paper. These data are particularly failure data. The principal author analyzed these data, which are primarily failure data. Observations, interviews, and physical artifacts and their analysis are different sources that allow the collection of evidence from these sources. Thus, we can investigate the consistency of the findings from these various sources of evidence. Further, we can also converge these pieces of evidence, a process known as data triangulation, to increase the robustness of the results [58].

B. *Checkland's Soft Systems Methodology*

Applying ST in a case study within the industry-as-laboratory enables Soft Systems Methodology (SSM) and

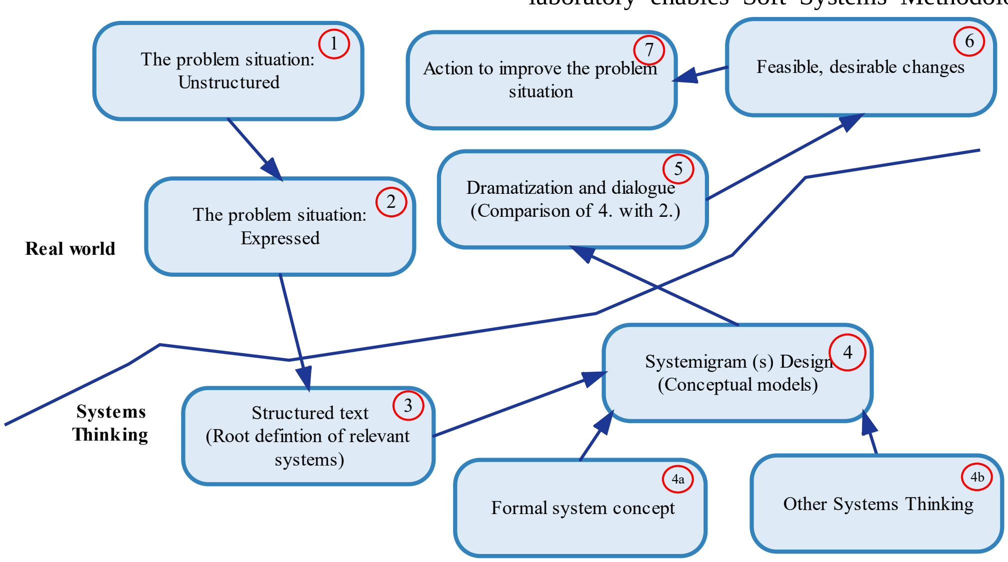

Figure 3. Checkland's soft systems methodology (SSM) is based on [11][15][54][56].

supports SE. Figure 3 depicts Checkland's SSM. We modified the method to be iterative and emphasized that there was no one right path. Further, we use the systemigram as a conceptual model, structured text as the root definition of relevant systems, and dramatization and dialogue as a comparison of steps 2 and 4. This modification was inspired by Sauser et al. (2011) [2], who called the SSM, which includes those modifications by Boardman's SSM (BSSM).

SSM allows for the inclusion of different perspectives and desirable outcomes of the case study. In addition, SSM bridges the real world and ST [11][15][54]. The SSM consists of the following seven steps, as Figure 3 visualizes:

Step 1: The Problem Situation: *Unstructured*. We have observed that the Company's request, as a part of the case study definition, is not wholly defined and validated early within the early phase of a complex socio-technical research project. The case can evolve and change based on many variables. These variables include the different perspectives and desirable outcomes of the various individuals involved in defining the case study.

Moreover, academia and industry emphasize different interests. For instance, the industry is more oriented toward maximizing profit and understanding how academia is more interested in research and the why and what [60]. The problem is defining the case study from different perspectives and including desirable outcomes from the various actors. Thus, early validation of the Company's request within the case study definition is a need within the early phase of the research project.

Further, the Company's request may touch the surface of the problem definition and not express the real need or problem definition that affects the case study within the research project.

In this step, the researchers conducted open-ended interviews with the Company, interactive workshops, and participant and direct observation. In addition, the primary author collected physical artifacts, which are failure data documents. The Company expressed through the interactive workshop a request. The Company's request is the start of the problem evolution. This request demonstrated the Company's vision through the visualization of a dashboard. This dashboard shows the condition of the Company's system through a traffic light code color. This dashboard has been called a Condition-Based Maintenance (CBM) system, which is the starting step toward developing a predictive digital twin system. In the workshops, we used Canvas in the form of A3s and pos-its to describe the problem situation and its aspects.

Step 2: The Problem Situation: *Expressed.* Alongside reviewing the literature, the researchers have created a text document on one page describing the Company's request within the case study, followed by meetings to verify the description.

Step 3: Structured text, known as the root definition of relevant systems. We moved to the ST domain by conceptualizing step 2. We used the CATWOE analysis in this step to understand the root definition of the APS, case study, and analyze it.

Step 4: Systemigram(s) design is a conceptual model. We developed two systemigrams models based on the output from step 3. In addition, we used other ST tools as input for the systemigrams. These tools include a context diagram, also known as an openness diagram, and a stakeholder interest map. Systemigrams capture the essence of the conceptual thinking for the Company's request within their case study.

Step 5: Dramatization and dialog by comparing steps 4 and 2. We moved back to the real world by comparing the systemigrams from step 4 with the Company's request, representing part of the case study description in step 2. Further, the authors dramatized the systemigrams via storyboarding in a Company workshop. The systemigrams as conceptual models were the basis for dialogue and discussion stimulation and for comparing the models with reality.

Step 6: Feasible, *Desirable Changes* We identified the feasible and desirable changes from Step 5 in a way that makes sense. These changes are translated into proposed leverage points and evaluated regarding the technical and cultural feasibility of the Company's request within their case study.

Step 7: Action to improve the problem situation. We called attention to the findings and applied them to our future case study work as part of the research project.

We repeated steps one to seven until the individuals involved in the case study reached a consensus. In other words, the process, including the steps, is repeated until the Company's need as part of the case study definition is verified and validated by experts from the industry (Company) and academia (scholars involved in the research project).

IV. RESULTS AND ANALYSIS

This section lists the case study results and analysis. The section starts with the tacit articulation and then the Systems Thinking implementation with its tools before it ends with the data analysis results.

A. Articulating Tacit Knowledge

We used SE and ST methodologies to articulate the Company's tacit knowledge in terms of data and visualization [49]. In the next subsection, we describe ST implementation and its tools, including the systemigrams from Company management and maintenance personnel perspectives (ref. III, B). These systemigrams are the data and visualization we used for the tacit knowledge articulation from the Company's key persons regarding the case study, focusing on Company management and maintenance personnel. On the other hand, Figure 4 visualizes the SE methodology implementation. We used this methodology implementation to structure a virtual board, i.e., the Miro board, for the workshops and interviews we conducted with the Company [61]. Figure 4 also represents the tacit knowledge articulation.

We first conducted interviews and workshops virtually due to Covid pandemic restrictions. Later, we conducted physical workshops and interviews. Due to confidentiality, we removed the most sensitive information from Figure 4. The point in Figure 4 shows how we constructed the digital board artifact, i.e., the canvas using SE methodology. Before the workshops and meetings, we sent a document, also called an artifact, that included a description of the research project, questions we wondered about, included among other, the aim of the workshops and meeting, and who we desired to meet, e.g., the Company's key persons. These key persons include Company management, system developers, and maintenance personnel. The initial workshops and meetings aimed to define the case study, including all its aspects. These aspects are also called embedded units of analysis [56].

Figure 4 includes the structure of the workshops, which contains six parts using a canvas in the form of an A3 and post-its. We portray these parts using yellow circles with a number. Part 1 includes the H-SEIF 2 research project descriptions, goals, and research questions. The Company we use as a case study in this research is a partner in the research project. Part 2 contains the Company introduction, description, visions, and so forth. Part 3 includes the Company's suggested aspects descriptions for the case study, the main challenges for these aspects, and expectations.

Furthermore, parts 4, 5, and 6 support the central part, i.e., part 3. Part 4 illustrates what, where, when, and how for the most significant case study aspect, e.g., data collation, identification, and analysis, to utilize data to enhance early-phase product development decisions. Part 5 discusses the critical stakeholders of the case study. Ultimately, part 6 illustrates the two approaches to utilize data toward digitalization, i.e., top-down and bottom-up, where we discussed the acting balance and iterations using the two approaches to achieve the intended goal(s) for the Company's case study. For part 6, the top-down approach starts by defining the questions we need to answer and then finding the appropriate data for these questions. The bottom-up approach begins by using data to exploit its hidden value.

In the workshops, the Company's key persons and scholars from academia from two universities that are partners in the research project have access to write and talk simultaneously. This access using post-its with different colors ensures that all participants, despite their personality (i.e., introvert or extrovert), express their ideas, beliefs, and thoughts based on their experience. This expression is essential to articulate the tacit knowledge within the Company's key persons toward the case study, all its aspects, and the academic scholar's tacit knowledge. This articulation is vital for defining the case study well.

Before the workshops, the academic scholars agreed on a workshop facilitator. The workshop's facilitator also ensured that all participants participated and had enough time to write, talk, or both. The facilitator also provided a warm environment during the workshop. After the workshops, we sent a one-page document to the participants, including the case study's definition and all its suggested aspects. We modified this document through several iterations until workshops participant, mainly the Company, verified and validated the document [62].

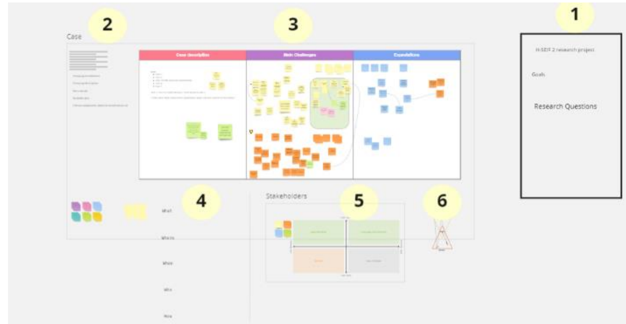

Figure 4. Canvas in the form of A3 and post-its we used to articulate the tacit knowledge where the Canvas's construction follows Systems Engineering methodology.

B. Implementing Systems Thinking in A Case Study

This subsection first illustrates the case study context by describing the SOI and systems boundaries. We demonstrate the system boundary using a context diagram. Further, this subsection shows the application of ST and other tools: a stakeholder interest map and CATWOE analysis. These tools are the foundation for systemigrams. The subsection ends by listing the possible leverage points from applying these tools after describing the systemigrams.

1) The Case Study Context

To understand the case study context, we first illustrate the SOI to understand the case study context. Further, we define the context for the SOI (i.e., the system boundaries through the context diagram). We categorize the variables for the system context using three categories: operation, development, and both contexts.

a) System-of-Interest (SOI)

As mentioned, the SOI for the case study is a semi-automated parking system (APS). The APSs are parking structures that store cars vertically to save place. The APS's design permits transporting vehicles from the entrance to the parking lot without the car owner being present. The degree of assistance from the car owners to the APS is the criterion used to distinguish between the fully and semi-automated parking system. The fully doesn't need any parking attendant, whereas the semi requires an attendant to drive or direct the car into the system [63]. The APS is a complex system because of its multitude of hardware and user interactions [13].

Figure 5 visualizes the SOI and its main parts. The main parts are: the gate, control unit, platform, and wedges. The end-users use the gate to open or close it to enter or retrieve their cars. The control unit controls the SOI and car owner, and maintenance personnel can use it as a panel to open or close the gate. The wedges are movable and help the end-users to park their cars in the correct position. Figure 5 also shows the SOI in 3D with a drive-in indication. This drive-in can be inclined or straightforward, depending on the building's architecture.

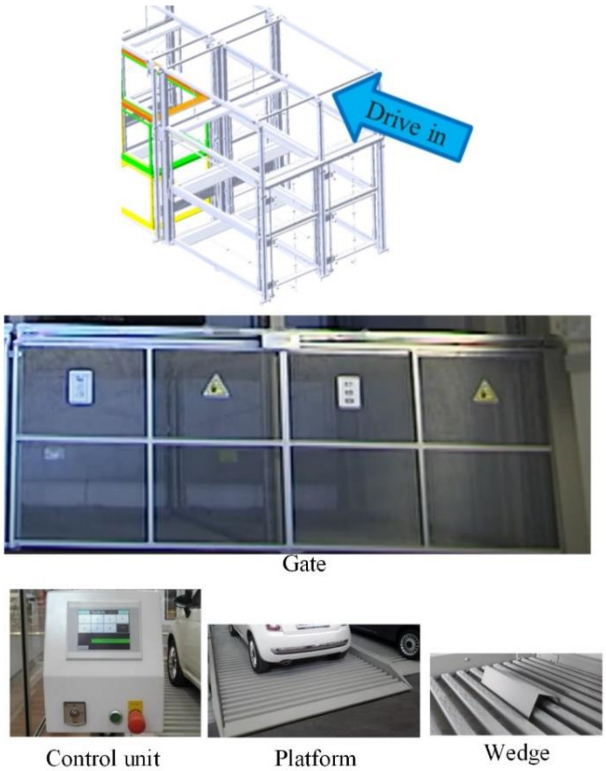

Figure 5. The System-of-Interest (SOI) and its main parts.

b) Context diagram: The system boundaries

We adopted the Gharajedaghis definition to define the SOI's boundaries [23]. Gharajedaghis defines system boundaries as "a subjective construct defined by the interest and level of influence and/or authority of the participating actors. The system, therefore, consists of all variables that could be sufficiently influenced by the participating actors". These boundaries aid in understanding the SOI in the context of their environment. Further, Gharajedaghis defines environment as follows: "the environment in which the system must remain viable consists of all those variables that, although affecting the system's behavior, could not be directly influenced or controlled by the participating designers."

Figure 6 portrays the system boundaries, also known as the context diagram or openness diagram, for the SOI, which includes three variables. We also categorize these variables according to operation, development, or both contexts. We used color text for this categorization, i.e., the green-color text refers to the variables that belong to the operational context. In contrast, the yellow-color text indicates variables that belong to the development context. The orange-colored text refers to variables that belong to both contexts, i.e., operational and development. The three variables are as follows:

Controllable Variables. The controllable variables are those that we can control. In this context, we can control the SOI (i.e., APS). We allocated the SOI in the innermost circle, which indicates that it is essential to act sufficiently to achieve the desired outcome.

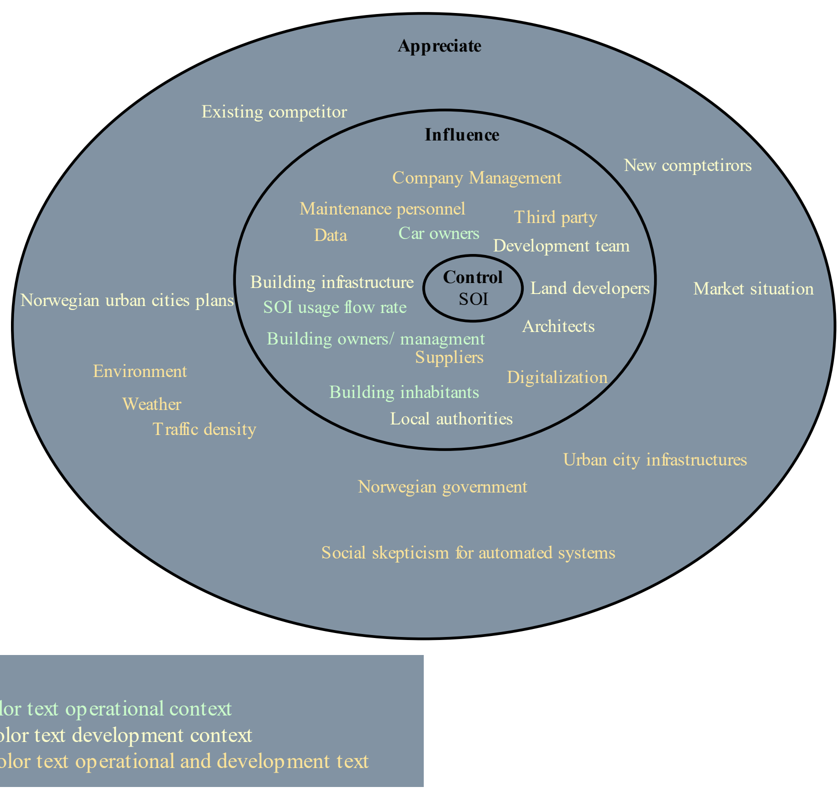

Figure 6. Context diagram of the System-of-Interest (SOI) with its variables.

Influencing Variables. Influencing variables are uncontrollable variables, but we can influence them. These variables include variables from operational, development, and both contexts.

The influencing variables that belong to the operational context are: car owners using the SOI, SOI usage flow rates, building owners or management, and building inhabitants, as they can affect the SOI operations. Further, we considered the following influencing variables in a development context: the development team, building infrastructure, local authorities, land developers, and architects.

Moreover, the variables that we included in both operational and development contexts are: *Company management*, as they are the decision makers for operation and development processes, *the third-party* as Company hires a third consultant party to develop or take part in the operation process, *maintenance personnel* as they maintain the SOI and take part in the development process due to their tacit knowledge, i.e., experience, thoughts, or beliefs, *suppliers*, as they supply the SOI with its part in the operational and development context, *digitalization* as we can digitalize processes or steps in a process that belong to the operational, development, or both contexts. For instance, a CBM system can be considered in the operational context. However, the analysis and prediction results from the CBM can also be used in the development context, that is, the next development cycle or version of the SOI.

In addition to the variables mentioned above, we included data as a variable in both operational and development contexts. Data depend on the data we identify, collect, and analyze. Data can belong to operation, development, or both contexts, depending on which data we identify, collect, and analyze. For instance, we can collect maintenance record data, also called failure data, from an operational context. We can use these data as feedback in the early product development process, which belongs to the development context.

Appreciating Variables. Appreciating variables are uncontrollable variables that we cannot influence. Thus, we must appreciate them. The appreciating variables that we considered to belong to the development context are: existing competitors, new competitors, market situation, and Norwegian urban city plans. On the other hand, the appreciating variables that we considered to belong to the operation and development contexts are: urban city infrastructure, social skepticism for the automated systems, the Norwegian government, and the environment, including weather and traffic density.

Even though we attempted to classify the three variables into operational, development, or both contexts, we noticed that it is not easy to have a clear distinction between those two contexts. One of the main reasons is that many variables, such as the data example we mentioned, can be used in both contexts. The same applies to other variables, such as the environment, that also affect or belong to both contexts.

2) Stakeholder Interest Map

Figure 7 visualizes the stakeholder interest map. Figure 7 also shows the SOI in the middle. Furthermore, we depicted the stakeholders with lines. These lines connect the stakeholders with each other and with the SOI. The lines are

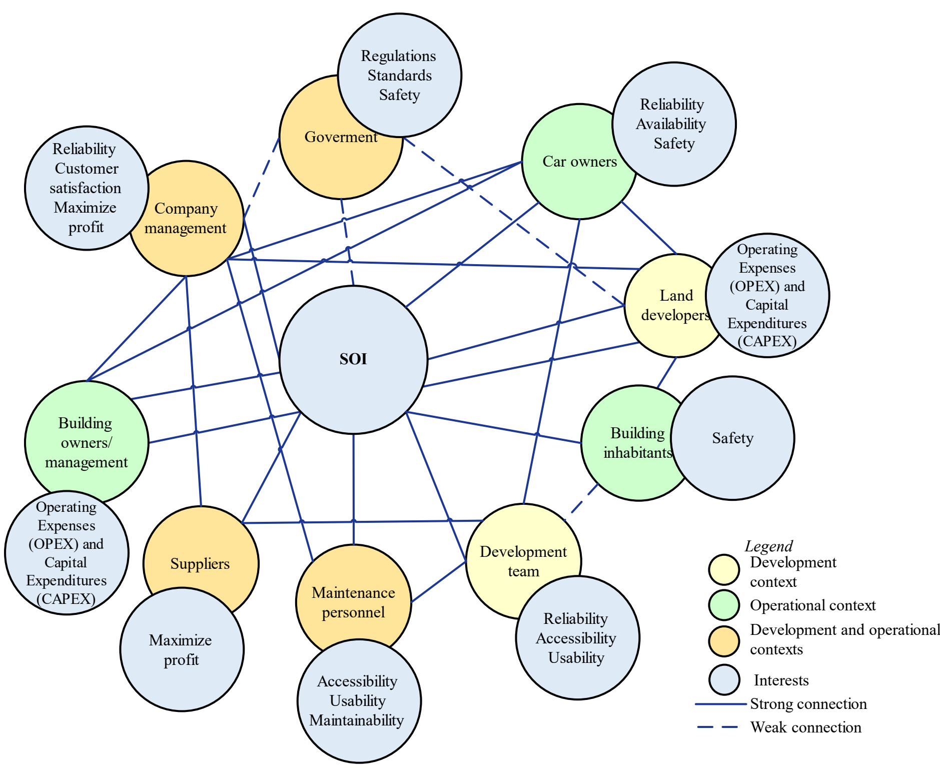

Figure 7. Stakeholder Interest Map

two types, i.e., solid and dashed lines. The solid line represents a strong connection, whereas the dashed line refers to a weak connection. This connection includes an interest in or influence on the SOI.

Moreover, we categorized the stakeholders into three categories, similar to the context diagram. These three categories are: stakeholders that are more involved in the development, operation, or both contexts. In addition, we listed the interests of these stakeholders in Figure 7.

Company management, maintenance personnel, government, and suppliers belong to operation and development contexts. The Company management strongly connects to the SOI, suppliers, and maintenance personnel. The interest of the Company management is maximizing profit, reliable SOI, and customer satisfaction. The Company management's customers are the land developer and building owners/ management. The customer of the customer, i.e., the end-user for the Company management, is the car owner. The interests of the maintenance personnel are: accessibility, usability, and maintainability. The suppliers' interests are: winning the contract to maximize the profit or Return on Investment (ROI).

On the other hand, the government has a weak connection to SOI and Company management. The government states the standards and regulations to ensure SOI's safety. These standards and restrictions affect the development and operation processes. However, the government is not involved in the details of SOI's development and operation to the same degree as Company management and maintenance personnel.

We categorized the land developers, development, and team within development contexts. The development team includes a third consultant party and key Company employees. The interests of the land developer are: Operating Expenses (OPEX) and Capital Expenditures (CAPEX) to maximize the Return on Investment (ROI), whereas the interests of the development team are: ensuring project success in terms of developing the SOI as reliable, accessible, and usable for the car.

Ultimately, the stakeholders that are more involved in the operation context are: building management or owners, building inhabitants, and car owners. The land developers often sell the SOI, including the building or estate, to building owners or individuals with shared ownership and select management for the estate. The Company is involved from the beginning, i.e., before the building is built. The building also includes inhabitants who either have no car or use traditional conventional parking, as some facilities include APS and traditional parking. The interests of the building management (owners of the building) are Operating Expenses (OPEX) and Capital Expenditures (CAPEX), whereas the interests of the building inhabitants are safety. The care owners' interests are reliable, safe, and available systems each time they use or park their cars.

3) CATWOE Analysis

To include the different key stakeholder perspectives, we used Customers, Actors, Transformation, Worldview, Owner, and Environment, called CATWOE analysis. This analysis is part of the SSM methodology. CATWOE analysis facilitates understanding the root definition of the system and analyzing it. The system can be a problem definition for a case study [24]. Figure 8 illustrates the CATWOE analysis. In this context, we apply CATWOE analysis to understand the purpose, need, or opportunity for the Company's SOI as a part of the case study from the two main stakeholder perspectives, i.e., Company management and maintenance personnel. Tables II and III show the results of implementing the CATWOE analysis regarding the Company management and maintenance personnel, respectively [1].

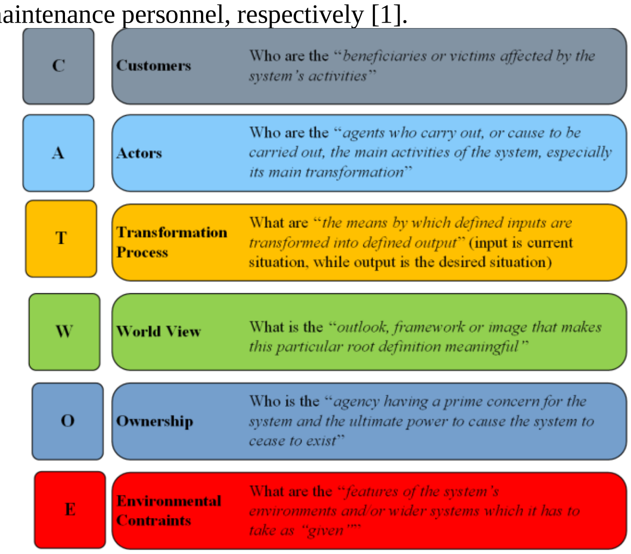

Figure 8. Customers, Actors, Transformation, Worldview, Owner, and Environment (CATWOE) Analysis.

TABLE I. CATWOE: COMPANY MANAGEMENT

Aspect	Description
Customers	Company management
Actors	Partners, suppliers, maintenance personnel
Transformation	Increase the reliability of the SOI
Worldview	Maximize profit
Owner	Company management
Environment	Urban cities

TABLE II. CATWOE: MAINTENANCE PERSONNEL

Aspect	Description
Customers	Maintenance personnel
Actors	Suppliers, Company management, car owners
Transformation	Maintenance process and method
Worldview	Increase reliability and availability of the SOI
Owner	Department heads of service and maintenance
Environment	The Automated Parking System (APS), buildings, cars, traffic density, weather, city infrastructure

4) Systemigram

A systemigram, also called a systemic diagram, is a graphical representation in the form of storytelling. The systemigram starts from the upper left with the SOI and ends on the bottom right. The SOI can be Company management, organization, or APS. The storytelling in the systemigram comprises visualized nodes and links. The nodes are names, and the links connecting these nodes are usually verbs. The main story of the systemigram is called the mainstay. The mainstay is usually a diagonal line in the systemigram.

Figure 9 represents the Systemigram from the Company management perspective. We also categorized the nodes in this systemigram into two colors: dark grey blue and light blue. The dark grey color refers to the mainstay, whereas the light blue indicates sources for (big) data. These sources include internal and external data sources. These sources include available stored data and possible sources to generate the needed data.

The mainstay for the first systemigram from the Company management perspective, i.e., Figure 9, is: "*Company management owns the SOI that in transition or manufacturing own parts that can include sensor(s), which permits anomalies observation remotely that aids mechanical failure detection and prediction in real-time that further allows continuous monitoring of the SOI that maximizes business viability that leads to maximizing profit."* Business viability includes many other nodes: increase SOI's reliability, availability, and customer satisfaction.

Company management is transitioning to manufacturing the SOI's parts using a team consisting of the Company's key persons and a third consultant party. This manufacturing development process includes installing sensor(s) that allow continuous monitoring towards predictive maintenance through a digital twin. This digital twin includes monitors showing the real-time condition of the SOI and its parts and predicting possible failures. The Company management believes that this vision reduces maintenance costs and maximizes business viability and profit.

The Company's key persons that are part of the development team include the project leader and maintenance personnel. The maintenance personnel own tacit knowledge about the SOI. The researchers can interact with the maintenance personnel to articulate the tacit knowledge in terms of visualization and data. The Company can also take part in this articulation. The maintenance personnel manually log the failure using an Excel file that includes a sheet for each paring installation. This file is called service-log or failure data. We consider these data as feedback data into early phase

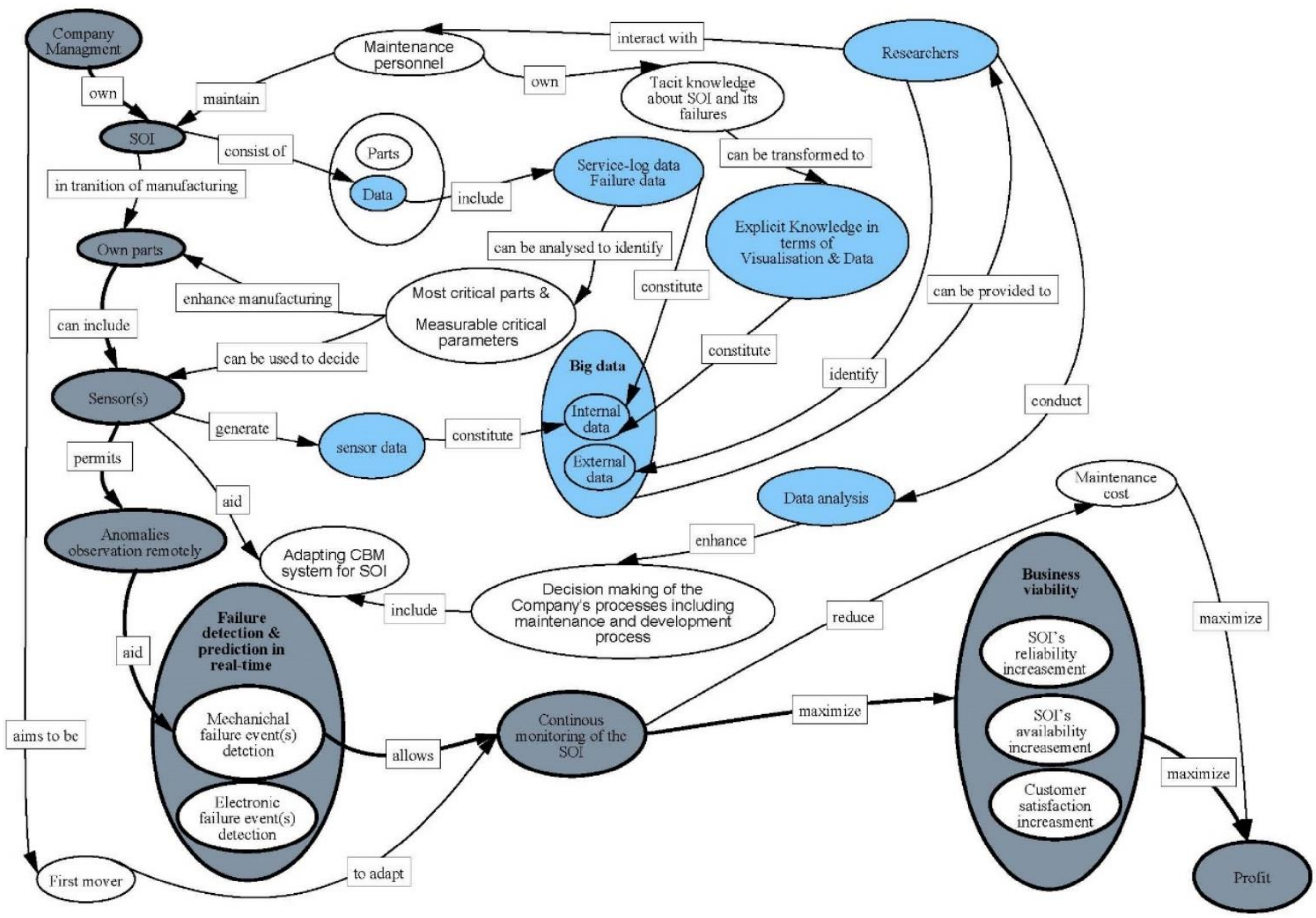

Figure 9. Systemigram from the Company management perspective.

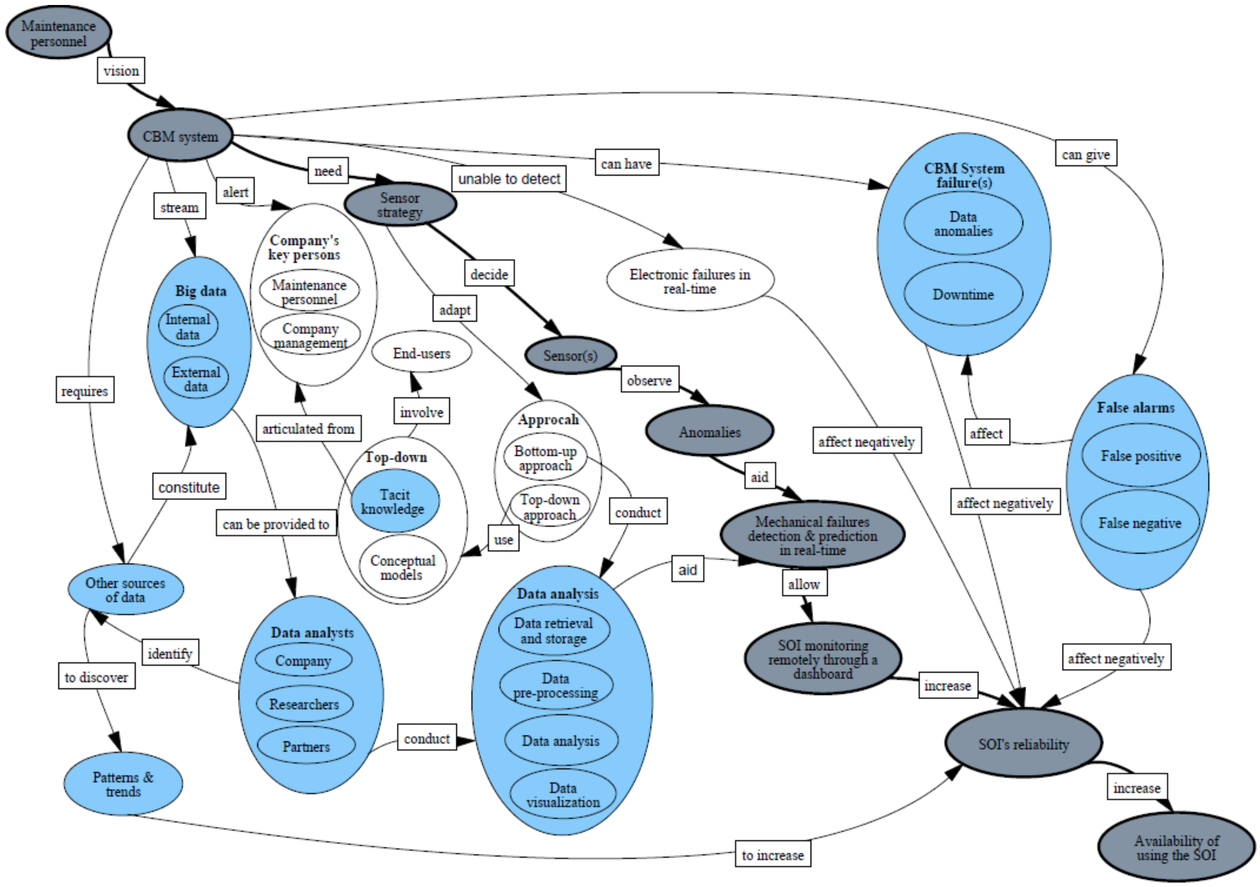

Figure 10. Systemigram from the maintenance personnel perspective.

product development as it is generated from the operation phase.

The tacit knowledge articulation and the failure data analysis can aid the development process, including manufacturing the SOI's parts. With tacit knowledge articulation and the data analysis results, the Company can identify the most critical parts and measurable critical parameters. The Company's decision-makers can use this identification to decide which sensors to install for which parts using a bottom-up sensor strategy.

The researchers can analyze and participate in articulating the maintenance personnel's tacit knowledge. The Company provides the data to the researchers and aids the interaction between researchers and maintenance personnel. The researchers identify the needed external data to investigate patterns and correlations between external and internal data. Internal data includes failure data and sensor or in-system data.

The internal and external data constitute the (big) data for the Company's case study. Analyzing the data enhances decision-making, including maintenance and development processes. This enhancement is moving toward more data-driven decision-making instead of a gut feeling. This data-driven methodology reduces maintenance costs and enhances the SOI's reliability, which maximizes profit.

Figure 10 visualizes the systemigram from the maintenance personnel perspective. Like the first systemigram, i.e., Figure 10, we categorized the second one into two categories. The first category, which has a dark grey color, represents the mainstay, while the other category has a light blue color that refers to the data in the Company's case study.

The Company's key person's vision, particularly maintenance personnel, is to have a Condition-Based Maintenance (CBM) system that can alert the personnel when the system detects failures. In addition, the CBM system should show the health condition in real-time of the SOI and its part through monitors. We can read the mainstay of the second systemigram as follows: *"Maintenance personnel vision CBM system. CBM system needs a sensor strategy that decides on the sensor(s) that observe anomalies, which aid mechanical failure detection and prediction in real-time that further allows SOI monitoring remotely through a dashboard, which increases the SOI's reliability and further increases the availability of using the SOI."*

The CBM system, which Company can invest in developing toward a digital twin, alerts the Company's key person, i.e., particularly the maintenance personnel. The strategy for the CBM system includes both top-down and bottom-up approaches. The bottom-up approach involves conducting data analysis, including failure data, sensor data, and other external data, such as environmental data.

The top-down approach consists of conceptual models and tacit knowledge articulation of the Company's key persons and end-user involvement. The end-user involvement gives the needed feedback in terms of notification when the end-users hear something not expected within the SOI operation, such as a sound of parts that need lubrication or are on their way to fatigue. This notification end-users can notify the Company in many ways, such as an app, picture, mail, or phone call. The Company, researchers, and partners can conduct conceptual models in many ways, such as using SSM methodology and ST tools such as systemigram, as we attempt in this research. In addition to other models, such as stakeholder interest map and workflow analysis using swimming lanes, we present the workflow analysis later (ref. Section IV, C).

In other words, the CBM strategy is an act of balance between the top-down and bottom-up approaches. This strategy aids in deciding which sensors to install for which parts to develop the CBM system. These sensors observe data point anomalies that assist in detecting and further predicting mechanical failure in real-time. The CBM system requires other data sources to verify and supplement the sensor's anomalies. These other data sources include environmental data, such as weather and traffic density.

The CBM system is also streaming data that constitute (big) data for the Company together with the other sources of data. The data analysts

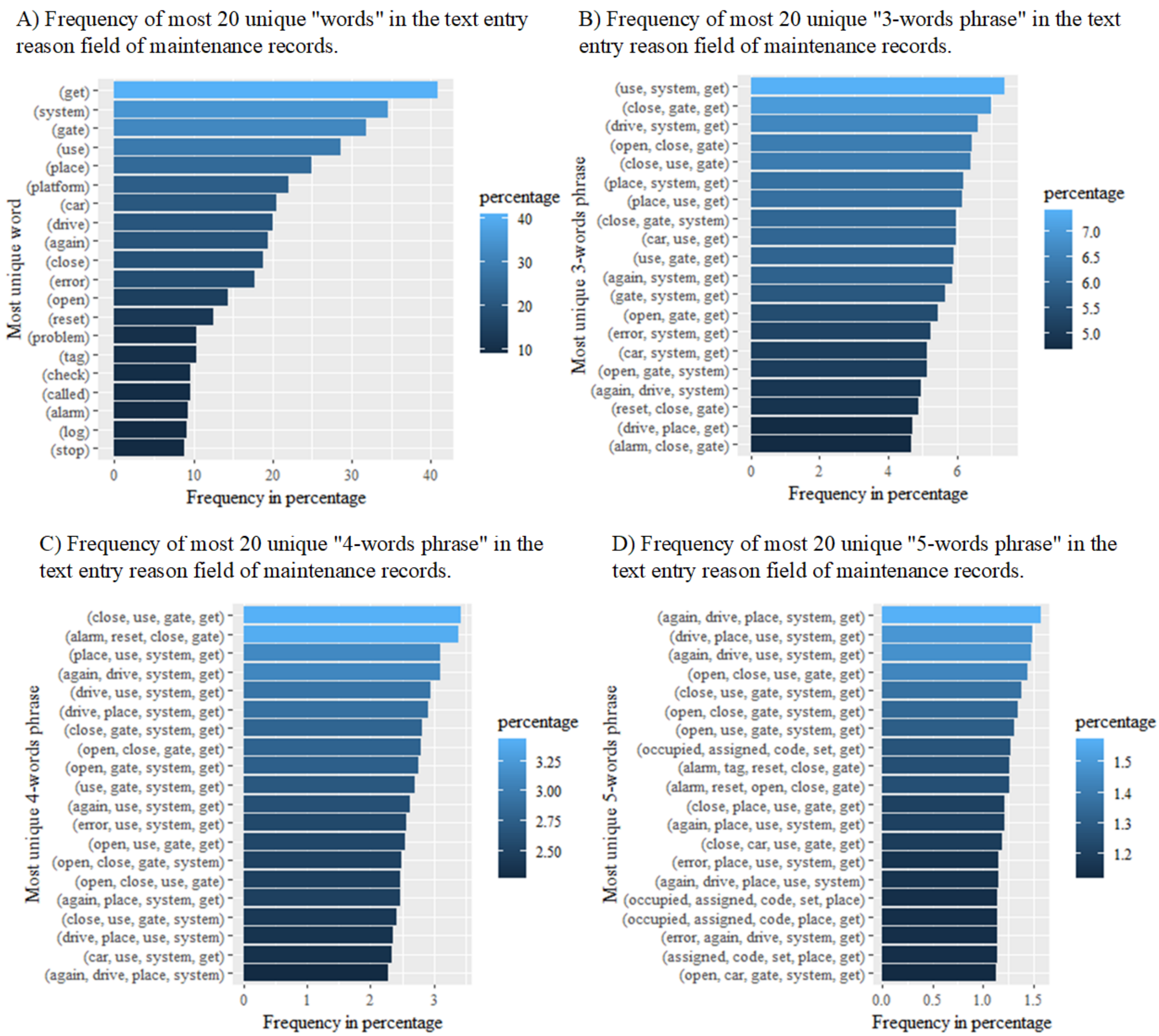

Figure 11. Most repeated unique words.

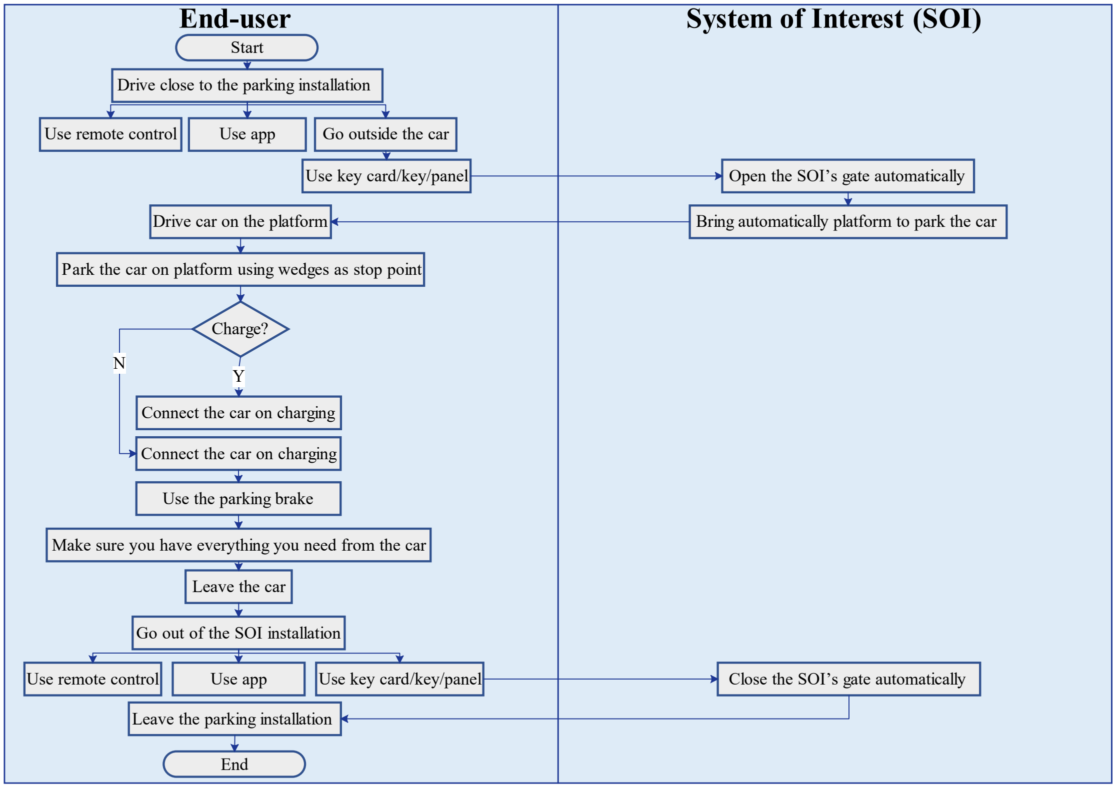

Figure 12. Workflow analysis uding swimming lanes for car entry.

include: the Company, researchers, and partners. The data analysis can identify the needed other data sources. Other data sources aid in discovering patterns and trends that increase SOI reliability and availability.

However, the CBM system cannot detect electronic failures like the Programmable Logic Controller (PLC). The CBM system can also give false alarms in terms of false positives and false negatives. False positive means the system provides an alarm or notification where there is no failure. On the other hand, a false negative means the system gives no

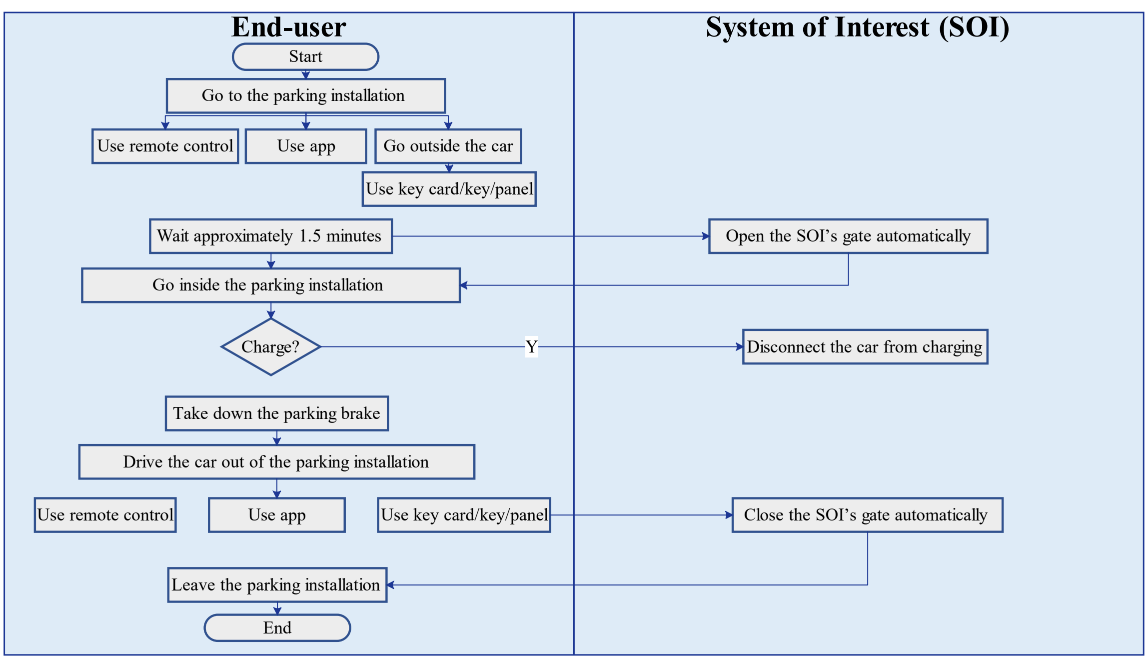

Figure 13. Workflow analysis using swimming lanes for car retrieval.

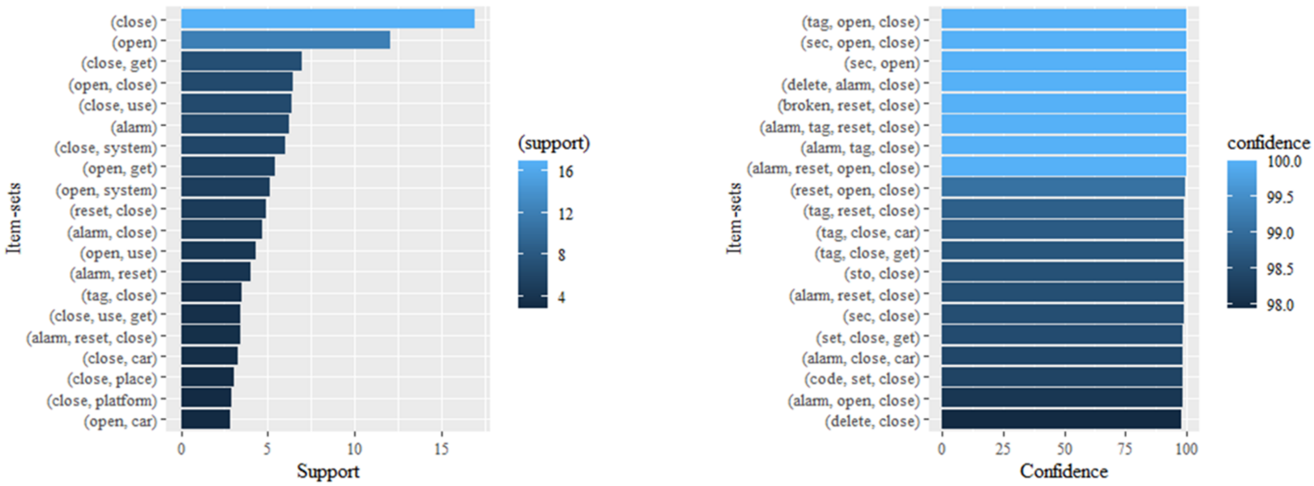

Figure 14. Most 20 unique frequent item-sets that appear with the gate in the failure events with its support and confidence values.

warning when there is a failure. These false alarms affect the CBM system in terms of failures. These failures include data anomalies because of false alarms. In addition, the CBM system failures include the system's downtime. The CBM system failures negatively affect the SOI's reliability.

5) *Systems Thinking Possible Leverage Points*

Implementing ST and its tools facilitates communication, understanding, and decision-making regarding a case study and its aspects. This case study is part of a complex socio-technical research project. We used the systemigrams to communicate with key stakeholders in academia and industry. The foundation for the systemigram is ST and other tools: stakeholder interest map, CATWOE analysis, and context diagram.

We developed two main systemigrams to visualize the two perspectives of the two main key stakeholders for this case study, i.e., Company management and maintenance personnel. The systemigrams facilitate decision-making regarding the development of a CBM system by visualizing all the significant aspects of this development. The systemigrams also visualized which approach suggested to the Company should adopt for the CBM's sensor strategy.

This approach is an act of balance between the bottom-up and top-down approaches. The top-down approach is tacit knowledge articulation and the use of conceptual models. The articulation involves the Company's key persons and end-users, while conceptual models include ST and its tools and other tools. The bottom-up approach uses data and data analysis.

C. *Failure Data Analysis Results*

We used the output of the NLP results as input for the association rule mining (i.e., FBGL), as mentioned above in the research methodology section. Figure 11 shows the results of using this mining. We used item-sets as one-word, three-word, four-word, and five-word phrases. Figure 11 depicts the 20 most unique frequent item-sets. Unique, in this context, refers to removing the duplication among failure events, i.e., if one item-set is repeated in one failure event (row), we remove its duplication.

Figure 11 shows that the most repeated unique words include: get, system, gate, use, place, platform, car, and so forth. The most frequent unique 3-word phrase, also called trigram, include: "use, system, get," "close, gate, get," "drive, system, get," and so forth. The most frequent unique 4-word phrases, also called 4-grams, include: "close, use, gate, get", "alarm, reset, close, gate", "place, use, system, gate". The most frequent unique 5-words, also called 5-grams, include: "again, drive, place, system, get", "drive, place, use, system, get", "again, drive, use, system, get", and so forth. We stopped the association rule mining using FBGL, also called n-gram analysis, as we got frequency results within one percent when we conducted the 5-gram analysis. We believe that the 3-gram analysis gives the needed information in this context.

This observation leads us to believe that the gate is the most critical subsystem within the SOI (i.e., the APS). Through interviews, workshops, and observations, we noticed that the maintenance personnel also used the system to mean a gate or segment or the whole system (i.e., APS). A segment is a collection of three gates, whereas the APS includes several segments depending on the building's architecture. Thus, even though the system comes before the gate, we conclude that the most critical subsystem is the gate. The next critical subsystem is the platform.

We also observe from Figure 11 that the open and close gates are the most frequent item-sets. In other words, "open" and "close" are the gate's most critical functions. In this context, we conducted a workflow analysis focusing on these gates' functions to investigate the end-users and the system's responsibility regarding these functions. These workflows for care entry and retrieval can be found in this publication [55]. We also developed the workflow analysis using swimming lanes to show the end-users and SOI responsibility more clearly regarding the gate's functions to open and close the gate with more details. Figure 12 and Figure 13 show these workflow analyses for car entry and retrieval, respectively. Further, we also notice that alarm, reset, and remote control are among the most repeated item sets or words.

Moreover, we dug deeper into the results showing the most frequent words or item-sets that come together with the "gate." Figure 14 portrays the 20 most unique frequent item-sets that appear with the gate in the failure events with its support and confidence values.

Support shows the percentage of occurrence of the item-sets, where the confidence indicates the percentage of the amount of time a given rule (if-then statement) is true among the dataset, i.e., failure events. This rule has two parts: an antecedent (if) and a consequent (then). The antecedent is the item-set we found among the datasets. The consequent is the item-sets found in combination with the antecedent [64].

Figure 14 (left) shows the support of antecedent item-sets, i.e., words in the y-axis where we determined the gate as consequent. We observe from Figure 14 (left) that if item-sets such as "close," "open," and "close, get," then we get the "gate" as a failure event, i.e., consequent.

Figure 14 (right) illustrates the confidence of the gate as a consequent. We notice that most item-sets, i.e., antecedents that co-occur with the gate as a consequent, include "tag, open, close", "sec, open, close", "sec, open", "delete, alarm, close", and "broken, reset, close."

The first antecedent, "tag, open, close," leads us to assume that issues with the tag the end-users use to open or close the gate trigger a gate failure event. The successive two antecedents, i.e., "sec, open, close," and "sec, open," lead us to assume that when the end-users use more time to open or close the gate in terms of sec, we get a failure event related to the gate. For the last two antecedents, i.e., "delete, alarm, close" and "broken, reset, close," let us assume that a broken signal to close the gate forces reset the whole system to close it again. In addition to one more assumption, an alarm must be deleted to close the gate. However, we can develop similar assumptions for more antecedents appearing in Figure 14 (right), but we believe we have mentioned the most significant ones.

1) Data Clustering

We used unsupervised machine learning to cluster the reason column in the failure data into three topics. We used the Gensim Python library for this topic modeling [65]. We got three topics with the most frequent words. The three topics included the following tokens (words) percentage: topic 1, 55% of the words, topic 2, 28.4%, and topic 3, 16.1% of the tokens (words). From the most 30 terms (words) included in the three topics, we assume that topic 1 indicates software issues. In contrast, topics 2 and 3 indicate human-machine issues (end-user failures) and mechanical issues (hardware failures), respectively. Figure 15 shows these clusters with their percentages.

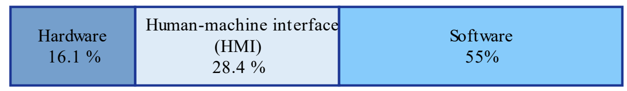

Figure 15. Failure data clustering into three clusters with their values.

D. Case Study Leverage Points

This subsection suggests recommendations for the Company based on applying the top-down and bottom-up approaches we implement in this case study. The top-down approach applies conceptual modeling via ST tools and other tools, whereas the bottom-up approach conducts failure data analysis. We visualize these recommendations in Figure 16.

The data analysis aids the decision-makers in the Company in reducing gut feelings. For instance, when we interviewed the maintenance personnel within the Company, different thoughts or beliefs were expressed regarding what is failing most, to which extent, and what causes the failure, e.g., users or the SOI. The data analysis answered such questions where the decision makers can base their decision on data-driven methodology reducing gut feelings. This feedback we got when we presented the analysis results in the Company

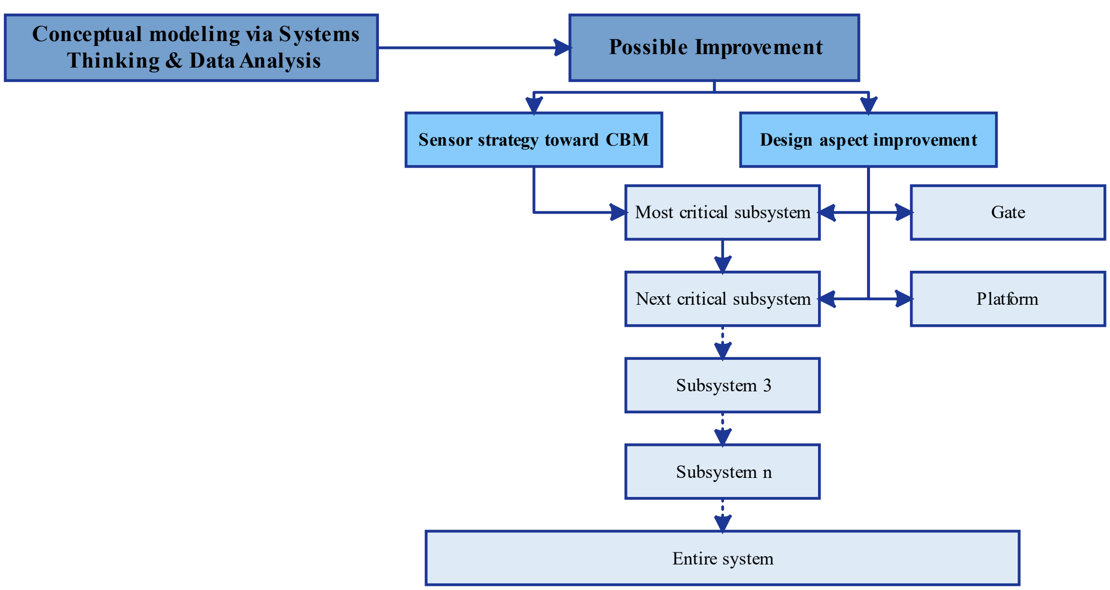

Figure 16. Case study leverage points.

during workshops. These workshops included Company management, maintenance personnel, and project leaders.

On the other hand, ST and other tools guide the data analysis. In addition, it facilitates communicating and understanding the problem domain, solution domain, and data analysis results. In this context, we developed systemigrams based on a stakeholder interest map, context diagram, and CATWOE analysis. Furthermore, ST triggers the development of other conceptual models, such as workflow analysis using swimming lanes, to understand and communicate the most failing critical part, which is the gate failures in this context, their natures, and their causes.

Based on applying both approaches, i.e., data analysis and ST, we suggest that the Company adopt a bottom-up sensor strategy to develop its vision regarding the CBM system and further digital twins. This bottom-up sensor strategy starts with the most critical subsystem, the next subsystem, and so forth. Data analysis aids in deciding the most critical failing subsystems instead of gut feelings. The failure data analysis results can also provide suggestions for design improvement. These improvements resulted from forming an explanation and seeing correlations and patterns among the failure data analysis results. However, we are collecting and analyzing other data sources, particularly weather data, to investigate the environmental factors and investigate correlations between these factors and failure events. This collection and analysis are still a work in progress.

V. Discussion

This section is divided into three subsections to discuss the article's research questions: RQ1, RQ2, and RQ3. The discussion section ends with limitations and further studies subsection.

A. Defining and Early Validation of a Case Study

The first research question, RQ1, is: "*How can we well-define and early validate a case study, including its multiple units of analysis using Systems Thinking and its tools?*". We developed two systemigrams from two perspectives. These perspectives include the Company management and maintenance personnel perspectives. We used ST and other tools as a foundation for these two systemigrams: stakeholder interest map, context diagram, and CATWOE analysis.

We believe that these two systemigrams facilitate defining the case study well and aid in validating the case study early in a complex socio-technical research project. Defining the case study well means we have an overview and include all aspects of the case study, also called multiple units of analysis. Early validation refers to the industry (Company) and researchers (academia) validating the case study. We conducted this validation through workshops and interviews. The feedback indicated that applying ST and its tools enhanced the understanding, communication, and decision-making in the case study and its multiple units of analysis. The decision-making consists of prioritizing the most significant unit of analysis for the case study among industry (Company) and academia (researchers). In this study, we prioritized failure data analysis to support ST implementations and discover hidden values among these failure datasets. The hidden value aided the Company towards data-driven decisions that aided in understanding more about the size and reasons for the failure events.

B. Tacit knowledge articulation

The second research question, i.e., RQ2, is "*How can we articulate tacit knowledge?*". We used ST and SE methodology to articulate the tacit knowledge from the Company's key persons. We used systemigrams based on ST and other tools, such as stakeholder analysis, context diagram, and CATWOE analysis.

We also used a canvas in the form of A3s and post-its in the virtual and physical workshops to articulate the Company's key persons' tacit knowledge. We used SE methodology to construct those A3 and post-its to ensure that all participants participated despite their personality, i.e., introvert or extrovert. However, we need to investigate further the effectiveness of the tacit knowledge articulation using the canvas in the form of A3s and post-its through a virtual platform.

This tacit knowledge articulation refers to the externalization mode in Nonaka and Takeuchi's model, which transfers tacit to explicit knowledge. This transformation contains an explanation of practices and beliefs. On the other hand, we observed that data analysis aids in creating knowledge, referred to as a combination mode by Nonaka and Takeuchi model [51]. The combination mode transfers explicit to explicit knowledge through restructuring the items already captured using deduction or induction.

C. Support Systems Thinking with data analysis

The third research question, RQ3, is "*How can we support Systems Thinking with data analysis?*" We collected and analyzed the Company's failure data to support the ST implementation for the Company's case study. ST and other tools, especially the systemigram, use a soft systems methodology (SSM). Thus these tools, including systemigrams, are considered conceptual models. In other words, ST and other tools cover the soft aspect, also called the top-down approach.

We complement the top-down approach with a bottom-up approach, also called the hard aspect. This aspect involves analyzing the failure data using machine learning. The feedback from the Company indicates that both approaches complement each other. Data analysis supports ST and reduces gut feeling. These gut feelings include the identification of the most critical subsystem that fails most, how often it's failing and why.

However, we need to iterate between these two approaches until the two approaches come into unity or until we accept the risk of moving to the next phase. We have started with data analysis and going back to the ST implementation in an iterative and recursive manner. This iterative and recursive manner aids in increasing the verification and validation of the case study's results in a complementary way. However, there is a need to investigate the number of details in both approaches, i.e., ST and data analysis. These details include investigating the number of nodes and links in the systemigrams. In addition, the number of figures showing the essential data analysis results and its way of visualization to ease communicating it to different stakeholders in industry and academia.

D. Research Limitations and Further Studies

One of the limitations of the presented paper is a lack of longitudinal research over multiple case studies. Any case study in complex socio-technical research would have several aspects that can affect the results. Therefore, we are starting to duplicate the same methodology with other industry partners, and the results seem promising.

Another limitation is analyzing additional data sources, such as sensor data from the Company for the same period of the failure data. Collecting these data when we conducted the case study was not technically possible. However, we are still in the process of further investigating the collection of these data with a third party. That data can affect the analysis and results and can be used for further research in this case study.

VI. Conclusion

Defining and validating a case study well and early at the beginning of a complex socio-technical research project is essential for the research project's success. This success ensures the Company's active participation and sharing of all needed data for the research. In this study, we used ST and its tools, including systemigrams, to define and validate the case study early. We used a stakeholder interest map, context diagram, and CATWOE analysis as a foundation for the systemigrams. We developed two systemigrams for the two main stakeholders for the case study, i.e., Company management and maintenance personnel. The Company's feedback indicates that using the systemigrams as conceptual models facilitates communication, understanding, and decision-making regarding the case study and its multiple units of analysis.

Moreover, using the systemigrams also aid in tacit knowledge articulation in terms of data and visualization. In addition, we used canvas in the form of an A3 and post-its for this articulation. We applied a SE methodology to construct this canvas. This articulation refers to the externalization mode in the Nonaka and Takeuchi model. According to the model, we refer to the data analysis as a combination mode. This mode creates knowledge through deduction or induction of already captured knowledge, which is the failure data analysis in this research.

We support ST and the implementation of its tools with data analysis. We collected and analyzed failure data using machine learning. We applied machine learning using the Frequent Pattern Growth Algorithm (FBGL) for association rule mining and the Gensim model to cluster the data. We considered the data analysis implementation the bottom-up approach, also called the hard aspect. Data analysis also reduces gut feelings and increases more data-driven early decisions. This data-driven methodology includes showing the failures, their size, and their causes.

In contrast, ST and applying its and other tools is the top-down approach or soft aspect. ST and other tools guide the data analysis. This guidance includes which strategy to adopt towards digitalization. The digitalization in this study refers to Condition-Base Maintenance (CBM) towards digital twins. Further, Systems Thinking aids in developing conceptual models to understand more and communicate the failures, their size, and their cause based on the data analysis results. In this study, we developed workflow analysis using swimming lanes for the most critical failing part, which is the gate, in this context, where data clustering shows these failures' natures, which are software, mechanical, and Human Machine Interface (HMI) issues. We conducted both approaches iteratively and recursively. The case study's results show that both approaches complement each other.

This study covers the lack of empirical research applying the two disciplines, i.e., ST and data analysis. ST provides the synthesis by investigating the case study, its aspects as a whole, and its relations among them. The data analysis goes in depth through reductionism, breaking the case study into more details. These two disciplines guide and support each other. Further, this research addresses tacit knowledge articulation in data and visualization using ST and SE methodologies in addition to the data analysis.

In further research, we plan to conduct longitudinal research applying the same methodology for multiple case studies. Furthermore, we plan to analyze additional data sources, such as in-system (sensor) data.

Acknowledgment

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Appendix A

Appendix A describes the data research methodology in detail. We collected failure data from the Company. The Company currently uses excel sheets to maintain logs about the failure events occurring in each semi-automated parking garage. Each excel sheets belong to a single installation. The Company installs semi-automated parking garages primarily for private buildings with fast-trained users.

The service-log data, also called maintenance records data, includes different parameters (columns) including, but not limited to: Date (for a maintenance event), time, telephone (for the maintenance personnel who investigated the failure event), place number (for which parking lot the failure event occurred), reason (possible reasons for the failure event), re-invoiced yes/no (if the failure event re-invoiced as it is not included within the maintenance agreement with the Company or not). These parameters construct the columns within the Excel sheets.

A. Natural Language Processing

Figure 17 visualizes a flowchart for the Natural Language Processing (NLP) methodology we conducted for the maintenance record data we collected from the Company. We use an introductory NLP analysis [14]. The NLP analysis we performed for the reason parameter (column) includes a description of the failure events. This description is a free text that is manually logged by the maintenance personnel. The NLP analysis included the following steps:

- Import data. We load all the data, which are failure events. These failure events are saved as an Excel file. Further, we import the text of interest, which is the reason parameter (column) in our case study.

- Tokenization. In this step, we divided the sentences into words, commas, etc. This step includes a sub-step that removes the numbers that appear directly after a word.
- Removing stop words. Stop words commonly occur in language, such as prepositions, pronouns, etc. These words do not add significant meaning to the sentences. We removed these words in this step.
- Stemming & lemmatization. In this step, we reduced the words to their origin, i.e., stem base or root form, also called a lemma. For instance, “engineering” or “engineers,” to its base word, “engineer.”
- Download the output file. We saved the results from the former steps into a Comma-Separated Values (CSV) file. Then, we downloaded the file for the next step, i.e., association rule mining.

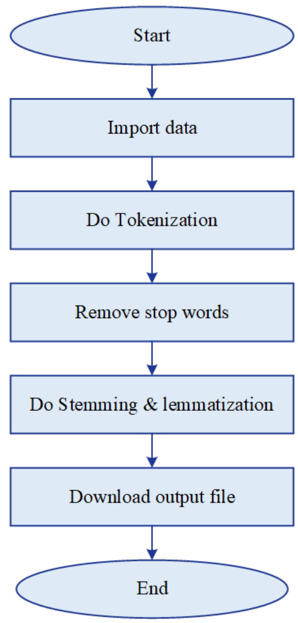

Figure 17. Flowchart for the Natural Language Processing analysis.

B. *Association rule mining*

Association rule mining involves machine learning models to analyze data. The association rule identifies frequent if-then associations, called association rules [64]. We used association rule mining to investigate patterns and co-occurrence among the words in the reason parameter, which is a text-free format [64][66]. We investigate these patterns by finding which words frequently co-occur after determining the most frequent word(s).

We used Frequent Pattern Growth Algorithm (FBGL). The foundation for this algorithm is the Apriori algorithm, where the FBGL is seen as Apriori’s modern version as it is more efficient and faster, giving the same results [67] [68]. The FBGL uses an expanded prefix-tree structure called the Frequent-Pattern (FB) tree to store compressed and essential data about frequent patterns. It is effective and scalable for mining the entire set of frequent patterns by Fragment Pattern growth (FP-tree) [69].

Figure 18 illustrates the steps before, during, and after the association rule mining using FBGL [66]–[68]. The steps are following:

- Import data. We import and read data from the last step in the NLP analysis.
- Pre-process data. We pre-processed the data. The pre-processing included removing duplicate words. This duplication is the same words repeated in the same failure events. Each failure event is organized in one row in the Excel file.
- Cluster using Spark. We used an open-source cluster computing tool called Apache Spark [70]. This local clustering aims at using the association rule mining using FBGL faster, i.e., getting results in less time.
- Read each item. In this step, the FBGL reads each item. The item in this context refers to each word in the loaded file as input for this mining. We chose the item or item-set to be a one-word, 3-words phrase (trigram), 4-words phrase, and 5-words phrase.
- Counting the occurrences of each item. In this step, the algorithm determines the occurrence of each item or item-set, which is words in this context.
- Determine support for each item or item-set. The algorithm determines the support for each item. Support reveals the frequency, or percentage, of co-occurrence of the item-set [64][67]. We based our decision on the value we

called minimum support, which is 0.01 (1%) in this case study. In other words, the item sets shall co-occur at least 1% among the dataset, i.e., failure event data.

- Support >= minimum support decision gate. The algorithm has a decision gate to decide whether to include the items in the frequent item-set. If the items do not fulfill the minimum support, we remove them.
- Add items to frequent item-set. In this step, the FBGL includes the items to the frequent item-set if the support for these items is higher than or equal to the minimum support value.
- Determine confidence for each item-set. The FBGL determines the confidence value for the added item-set from the former step. Confidence reveals how frequently a rule is applied. The conditional probability of the right-hand side given the left-hand side is another way to put this. This rule can be, for instance, which words come to the right of a specific word. Another example is which items (words) come together among the dataset, i.e., failure event data. We set up the value for the confidence to be 0.6 (60%) [64][67].
- Confidence >= minimum confidence. The algorithm had another decision gate to decide to include the item-set. If the item-set does not fulfill the minimum value for the confidence, we remove it.
- Add item-set to the frequent item-sets. The FBGL adds the item-set that fulfills the minimum value for the confidence to the frequent item-set.
- Order the item-sets based on occurrences. The FBGL order the item-sets based on their occurrences.
- Create the tree for the item-sets. The FBGL creates the tree for the item-sets based on their ordered co-occurrences. Each item(s) (word(s)) is a node in the tree.
- Write results to a file. We added the results (item-set) from the former step to a CSV file.
- Visualize results. We visualized the results (items-set). This visualization includes all the selected items or item-sets, i.e., the most frequent unique word, most frequent unique 3-phrase words, 4-phrase words, and so forth.
- Translate results. After the visualization, we chose the most significant results based on feedback from the industry and academia practitioners and the Company's key persons. After this input, we translated the results from Norwegian to English. Ultimately, we visualized the most significant results we show in this study.

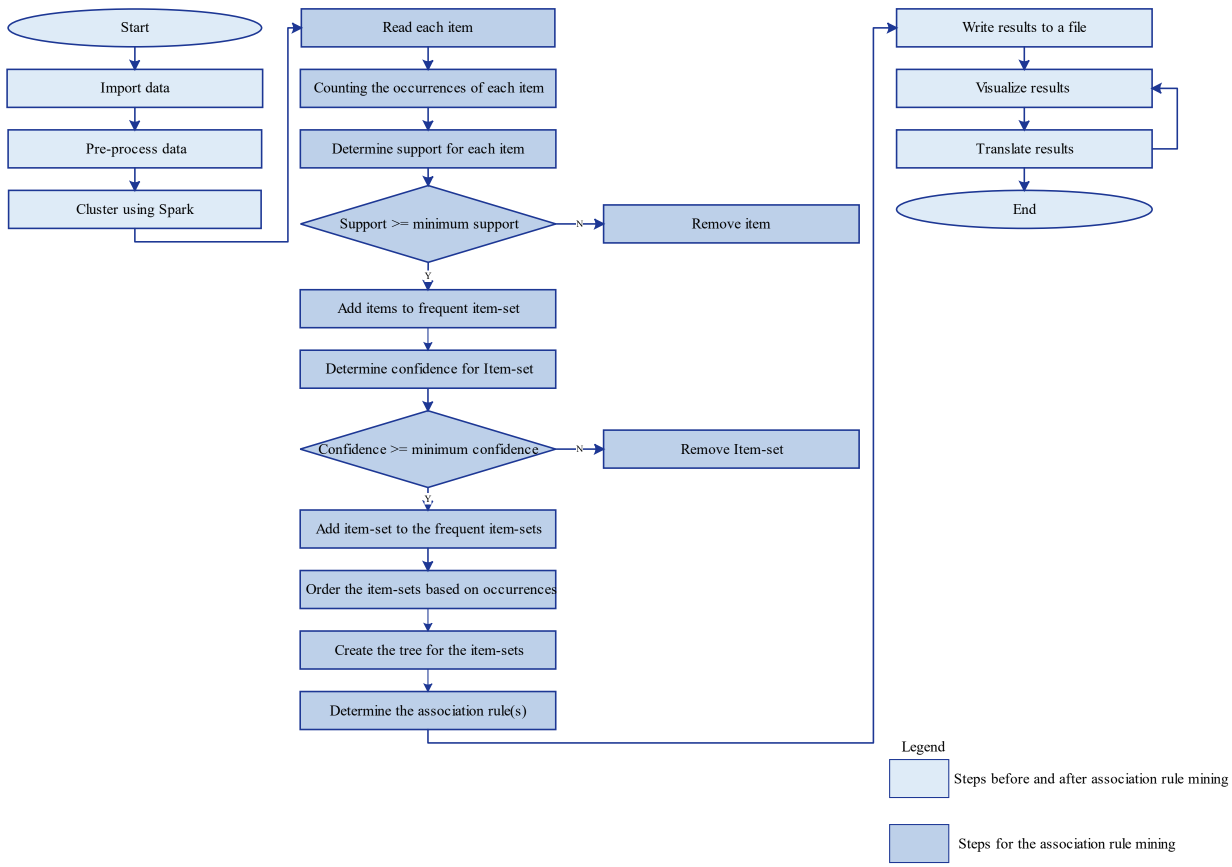

Figure 18. Flowchart showing the steps during, before, and after Association rule mining using Frequent Pattern Growth Algorithm (FBGL).

Pinbone Detection of Japanese Shime-Saba by Near-Infrared Imaging

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***Abstract*—There is a growing demand for new analytical techniques to manage the presence of fish bones more effectively. The detection of fish bones involves human inspection using touch and vision, which can lead to misjudgment. Many studies utilize X-ray machine vision approaches to effectively detect fish bones in quality control processes. However, this approach requires complex devices and carries the risk of radiation exposure. In this study, we attempted to detect the pinbone tip locations of shime-saba by using Near-Infrared (NIR) machine vision to highlight those features and quantify them based on image geometry and neural networks. The vinegar added to the shime-saba softens most of the bones, but the pinbones remain tough and need to be removed. Our approach is as follows. At first, the fish fillet is photographed with NIR transmitted through the fish fillet. The resulting image is correlated with the Gaussian template image. Quadratic surface equations are performed on the automatically defined Region of Interest (ROI) for this image and the convex-up shapes are selected as candidates for the pinbone tips. Rectangular areas (sub-images) of ten candidates are extracted and a Convolutional Neural Network (CNN) is constructed using these sub-images to determine the presence of pinbones. In the experiment, 95 samples of shime-saba fillets were captured in NIR, and 950 sub-images (225 contained pinbones) were extracted to train the CNN model. As a result, the CNN model was able to determine the bone with 84.9% accuracy.**

Keywords-fishbone; near-infrared imaging; bone detection; image geometry; convolutional neural network.

I. INTRODUCTION

There is an increasing need for improved quality inspection and visibility into the food supply chain to ensure food safety, quality, and traceability. This paper is an extension of our previous work on an automated method for detecting pinbones of shime-saba [1], a traditional Japanese fish dish.

Sushi and sashimi are among the most famous Japanese dishes. Such fishery products have had a significant influence on the Japanese diet for centuries. In addition to fresh fish, there have also been many seafood products developed for long-term preservation. Traditional Japanese seafood preparations include shime-saba (mackerel marinated in sugar, salt, and rice vinegar) and dried or salted fish. Hachinohe City in Aomori Prefecture is home to shime-saba, the first city in Japan to begin producing this fish dish in 1968. Although the number of mackerel landings is on the decline, production of shime-saba is on the rise. However, this growth is difficult to maintain in Japan due to a chronic shortage of human resources, requiring the automation of production processes.

To increase efficiency in the food industry, methods are being developed to automate production processes [2]. Robotics may play an important role as a solution. However, compared to other industries, the food industry has been slow to adopt robotics. The use of robots is expected to bring many tangible, intangible, social, and economic benefits [3]. The risks associated with sanitation and safety, as well as high labor and social costs, will promote the adoption of robots in the food industry.

The fisheries industry has traditionally been a labor-intensive sector and required skilled staff to process the fish into consumable products. Processing included filleting, trimming, peeling, visual inspection for parasites, and quality control [4]. Another process of trimming is the removal of pinbones. The pinbone can be removed by hand because its attachment tends to weaken after rigor.

The Japanese food industry is actively introducing robots to the market. However, it is difficult for small and medium-sized companies to introduce robots for processing typical fish on their own. In addition, the processing of shime-saba requires human handling to remove the pinbones that remain on the fish fillet. The vinegar added to the shime-saba softens most of the bones, but the pinbone remains tough and needs to be removed by hand. Since pinbones are difficult to see, this job is physically demanding because it involves touching the fish fillet, sensing the presence of pinbones, and then removing those bones with tweezers. It also requires more workers to ensure production capacity. The manual removal of the remaining pinbones from the shime-saba can be seen in Figure 1. These bones are in the middle of the cross-section of the filleted fish body. Since the cross-sectional height of shime-saba is only about 1-3 cm, deboning automatically from that position is considered challenging.

The purpose of this study is to improve on our previously developed image sensing system for detecting the pinbone tips of shime-saba to assist in deboning robots [1]. The new system automatically detects the tip of the bone by analyzing features from Near-Infrared (NIR) images of the fillet of shime-saba. Pinbone detection is performed in two stages: selection of local convex-up regions based on mathematical quadratic surfaces and determination of the regions containing pinbone tips based on Convolution Neural Network (CNN). Finally, the implementation of this system is described and further improvements in detection accuracy are discussed.

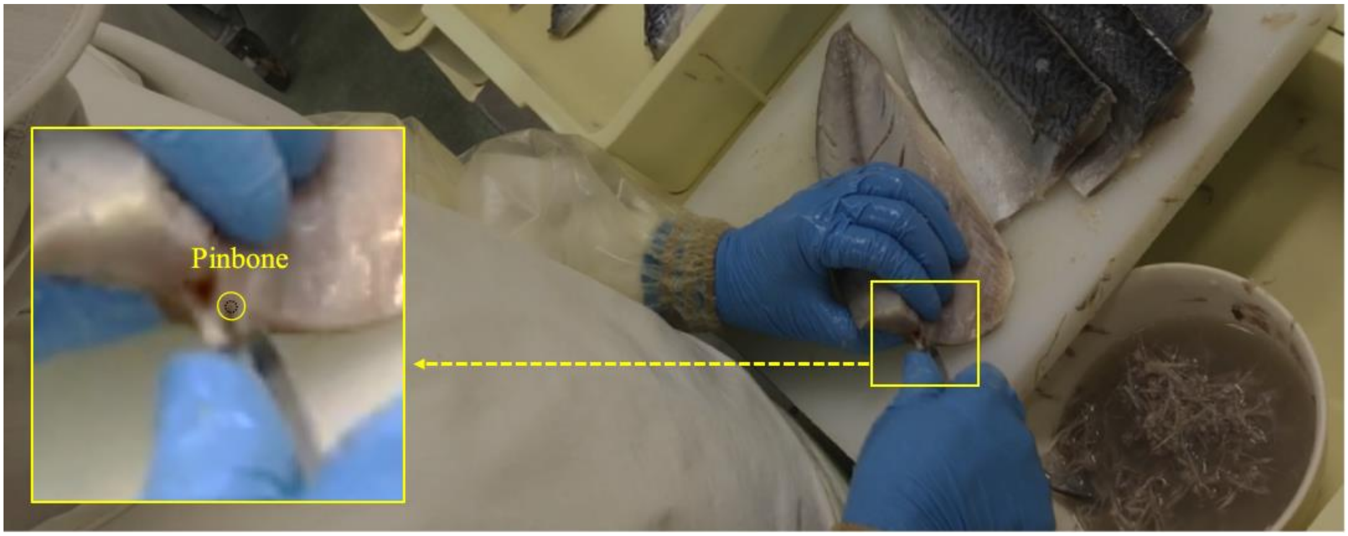


Figure 1. Manual removal of the pinbones remaining in the middle of the cross-section of the fillet.

The rest of this paper is organized as follows. Section II describes related works on fish bone detection using image sensing techniques. Section III describes our proposed methods for detecting pinbone tips from NIR transmitted images. Section IV describes our experiments and summarizes the results. Section V provides a discussion of improving the determination of areas that limit the analysis area for efficient pinbone tip detection. Finally, section VI concludes our work.

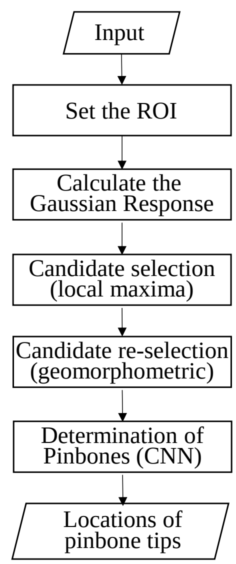


Figure 2. Detection of pinbone tips for this study.

II. Related Works

Traditionally, removing bones from fish fillets has involved the use of tweezers or needle nose pliers. Currently, hand-held pinbone removers are available and allow for easy deboning manually. To remove bones using these tools, the tip of the bone must first be located. Hence, finding the tip of the bone is an important step in automating the deboning process.

Various applications using image sensing inspection have been developed to ensure food safety. For detecting fish bones, image sensing techniques such as X-ray, Ultraviolet (UV), and NIR spectroscopy have been proposed. Mery et al. developed an X-ray machine vision approach to detect bones in fish fillets [5]. Their device is a digital radiography system consisting of an X-ray source and a flat panel detector. Filter banks including Discrete Fourier Transform (DFT), Discrete Cosine Transform (DCT), and Gabor were used to extract features from the resulting X-ray images. The results showed that by photographing the fish bones, which are arranged in strips and range from 14 mm to 47 mm in length, these bones can be detected with a high accuracy. Andriiashen et al. introduce a processing method for unsupervised foreign body detection based on dual-energy X-ray absorption measurements. Their method results in improved X-ray-based bone detection [6]. Wang et al. investigated the fluorescent properties of cod bone under UV irradiation and found that the optimum wavelengths of excitation and emission were 320 nm and 515 nm. They were the first to develop UV fluorescence-assisted candling for detecting fish bones, but the detection accuracy was lower than that of X-ray-based techniques [7]. Wei et al. used infrared spectroscopy to identify fish bone contents in surimi. The absorption peak in the infrared spectrum at around 9,890 nm wavelength was observed from fish bones [8]. Song et al. proposed a fish bone detection based on Raman hyperspectral imaging technique to improve detection rate and achieve automatic detection [9]. This technique was found to effectively detect fish bones down to a depth of 2.5 mm.

The above optical sensing at various wavelengths has been used to bring up the feature values of fish bones to locate the position of the bones in the body of the fish. However, putting

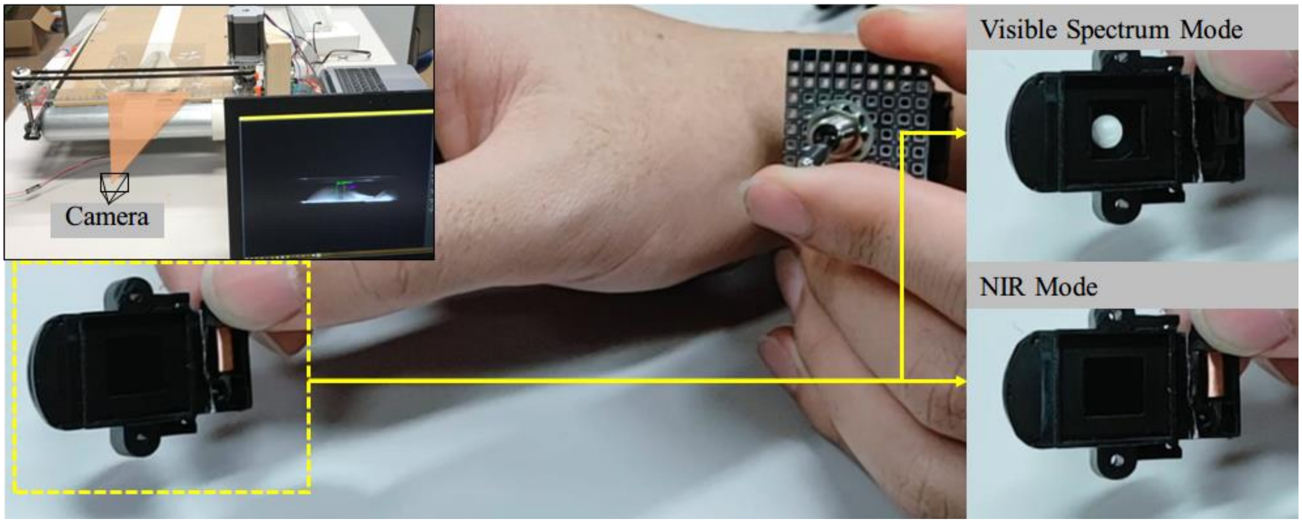


Figure 3. The device for NIR imaging in this study.

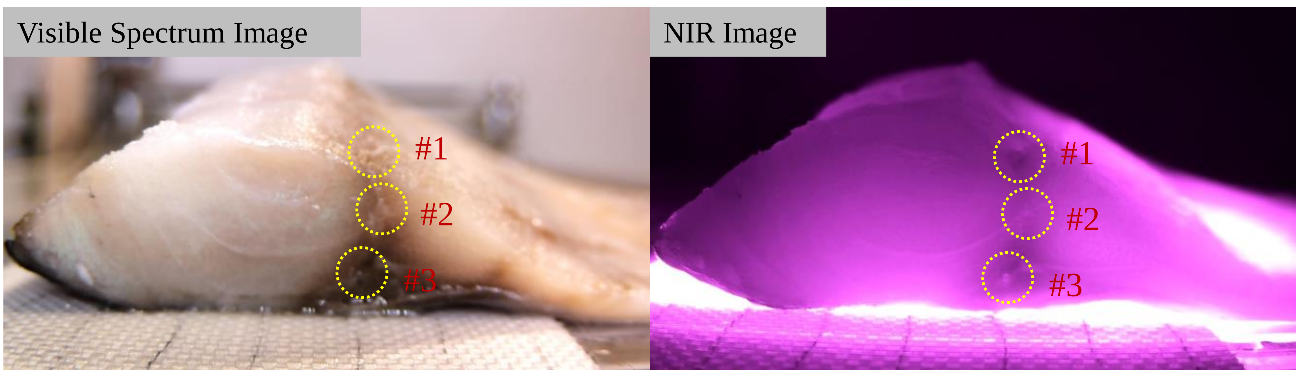


Figure 4. Three bones in the shime-saba.

these technologies to practical use in food processing facilities is problematic due to their high cost. Furthermore, while it can detect bones of a certain length, it is not capable of detecting objects where only the tip of the bone can be seen. In contrast, the NIR-based approach proposed by Prima et al. was able to highlight the presence of pinbone tips by image correlation between NIR and Gaussian template images [1].

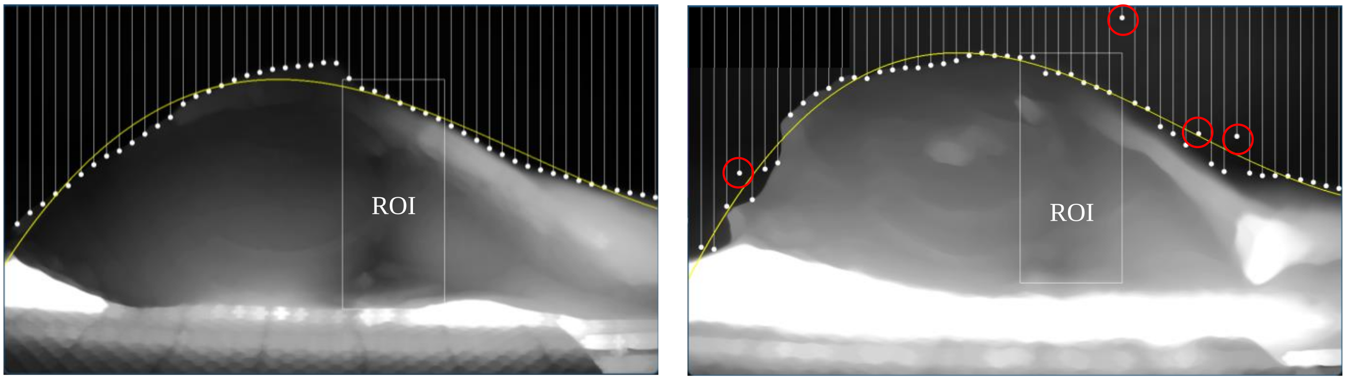
III. Methods

In this study, we focus on the broad application of NIR to food analysis, based on various sample presentation techniques [10]. In addition to reflection, NIR absorbed and transmitted from the sample may be used to detect the presence or absence of pinbones in the fish fillet. Here, we attempt to detect the tips of pinbones by photographing the NIR transmitted through the fish fillet.

Figure 2 shows an overview of our pinbone tip detection. After capturing a fillet of shime-saba, the region of interest (ROI) where the pinbone is likely to be located is estimated. Since the pinbone of the shime-saba remains in the center of the cross-section of the fillet, assigning this region as a ROI reduces the processing cost of its detection. This ROI estimation involves locating the backbone of the fillet. The NIR image within the ROI is then correlated with a predefined Gaussian template image to produce a Gaussian response image. Regions with maxima in the response image are selected as candidates for those consisting of the pinbone tip. Geomorphometric features are calculated for these regions, and regions with convex-up features are selected as final candidates. Finally, a CNN model is built based on these regions, and the presence or absence of pinbone tips in each region is determined.

A. *Image Acquisition*

The device for NIR imaging in this study is shown in Figure 3. The camera can capture images in the wavelength range from visible spectrum to NIR spectrum. To obtain images in each spectrum, a dynamic infrared filter is attached to the camera lens. Arduino hardware and software were used to switch the filters. By switching these filters electronically, both visible and NIR images of the fillets can be taken at the same position and orientation. For the NIR source, eight 840 nm NIR LEDs were used. The LEDs were arrayed beneath the conveyor belt. The camera resolution is 1280x720 pixels.



(a) Proper detection of the upper boundary points of the fillet (b) Incorrect detection of a part of the upper boundary points of the fillet

Figure 5. Determining the ROIs.

As shown in Figure 4, there are a maximum of three pinbones to be deboned. The presence of these bones is not clear in the visible spectrum image, so deboning staff must touch the fillet with a tweezer to check for their presence. In contrast, the NIR image reveals features at the tip of the pinbone. The tips of the pinbone appear to be locally bright and to have a convex-up surface in the NIR image.

B. *Determining the ROI*

In the cross-section of the shime-saba fillets, the pinbone tips to be detected are known to be located on the backbone of the fillet relative to the stomach. Since the most raised portion of the fillet is where the backbone was originally located, identifying this area will lead to the identification of the ROI. To automatically identify this location, a vertical edge detection filter (Sobel) is applied to the near-infrared image of the fillet, and the resulting edge image is scanned from top to bottom for all columns to find points where pixels exceed the threshold value. A cubic polynomial

$$f(x) = Ax^3 + Bx^2 + Cx + D. \quad (1)$$

is applied to these points to estimate the shape of the upper part of the fillet. Here, x, y are the coordinates of the points obtained from scanning. A to D are the coefficients for the cubic polynomial calculated by the least squares method. If the location of the maximum of the curve of the cubic polynomial is on the left side of the fillet image, the stomach is considered to be on the right side, and vice versa.

The resulting ROIs are as shown in Figure 5. Despite the presence of some incorrectly detected upper boundary points of the fillet (red circles) as shown in Figure 5(b), the cubic curve approximately traces the fillet's boundary (yellow lines).

C. *Gaussian Response*

To enhance the features of the bone tips in the NIR image, this image is correlated with a Gaussian template image. The formula of a Gaussian function in two dimension is

$$f(x, y) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2+y^2}{2\sigma^2}} . \quad (2)$$

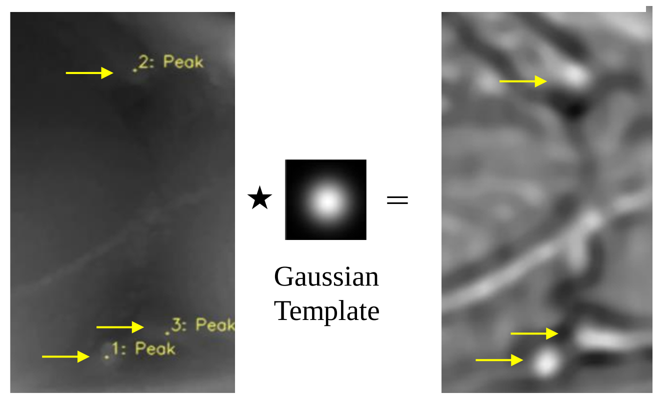


Figure 6. The response image obtained by pre-processing.

where x, y is the distance from the origin in the horizontal and in the vertical axes, respectively. σ is the standard deviation of the Gaussian distribution. As shown in Figure 6, the response image obtained shows that the center of the image is bright in the region at the tip of the bone. If the brightness of this image is taken as an elevation, the region at the tip of the bone can be thought of as a convex-up surface. The extent of the convex-up structure can be adjusted by changing the size of the Gaussian template image. For this study, the size was empirically determined to be 45 x 45 pixels with $\sigma = 5$ pixels.

D. *Rectangular Areas of Pinbone Tip Candidates*

The rectangular area centered on the brightest spot of the response image is selected as the candidate area (sub-image) for the pinbone tip. This spot is extracted by calculating the local maxima of the response image. A threshold is set as the distance between a point of maxima and the next point of maxima. Here, the size of the area is set to 45 x 45 pixels and the minimum distance between the points of maxima is set to 20 pixels.

E. *Geomorphometric Features of Pinbone Tip Candidates*

We developed a morphometric characterization algorithm to determine geomorphometric features (e.g., peaks, pits, ravines, or ridges) from previously described rectangular

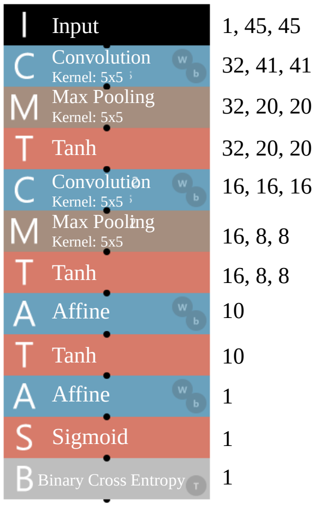


Figure 7. The CNN used for this study.

areas of the pinbone tip candidates. The quadratic surface is fitted to the image within a moving local analysis window using least-squares [11], with the general equation being

$$z = f(x, y) = Ax^2 + Bxy + Cy^2 + Dx + Ey + F. \quad (3)$$

where (x, y) is the location's coordinate, z is the pixel value calculated by the quadratic function, and A to F are the coefficients of the quadratic function calculated by the least squares method. By analyzing the second-order coefficients A to C, the shape of the quadratic surface can be characterized as follows.

$$\text{Elliptic paraboloid:} \quad B^2 - 4AC < 0 \quad (4)$$

$$\text{Hyperbolic paraboloid:} \quad B^2 - 4AC > 0 \quad (5)$$

$$\text{Parabolic paraboloid:} \quad B^2 - 4AC = 0 \quad (6)$$

Here, if A=B=C=0 then the quadratic is a plane. Equation (2) divides the quadratic surface into convex-up and concave-up. If the center of the convex-up surface is within the analysis window, this surface can be determined as the peak. As shown in Figure 4, the pixel of the pinbone tip is brighter than its neighbors, which means that this pixel represents the convex-up (peak). Hence, this property can be used to determine the location of the pinbone tips from the response image.

F. *Determination of Pinbone Tip Using CNN*

Regions with convex-up features do not necessarily contain pin bones. We introduce a CNN that determines the presence of pin bones among those regions. Our CNN architecture is shown in Figure 7. This network was built using the Neural Network Console [12], an engineer-oriented deep learning framework developed by Sony Group Inc. The input to the CNN is a 45x45 rectangular area of the pinbone candidate. Signals are passed through a two-stage network consisting of convolution, maximum pooling, and tanh activation function. The first stage produces 32 maps and the second stage 16 maps. The results are fully concatenated and the presence or absence of pinbone is determined by binary cross entropy. The Mean Squared Error (MSE) is used as the loss function for the network optimization process.

To summarize, the process to build a dataset of pinbones in shime-saba fillets is as shown in Figure 8. The first process is to find the boundary points (white circles) between the top point of the fillet and the background based on the edge intensities calculated from the input NIR image. From these points, a cubic curve (yellow line) is approximated to find the highest point of the fillet. The ROI is then placed at the same height as the top point in the stomach direction. Ten rectangular areas of candidate pinbones are automatically extracted. These areas are assumed to have both local maxima

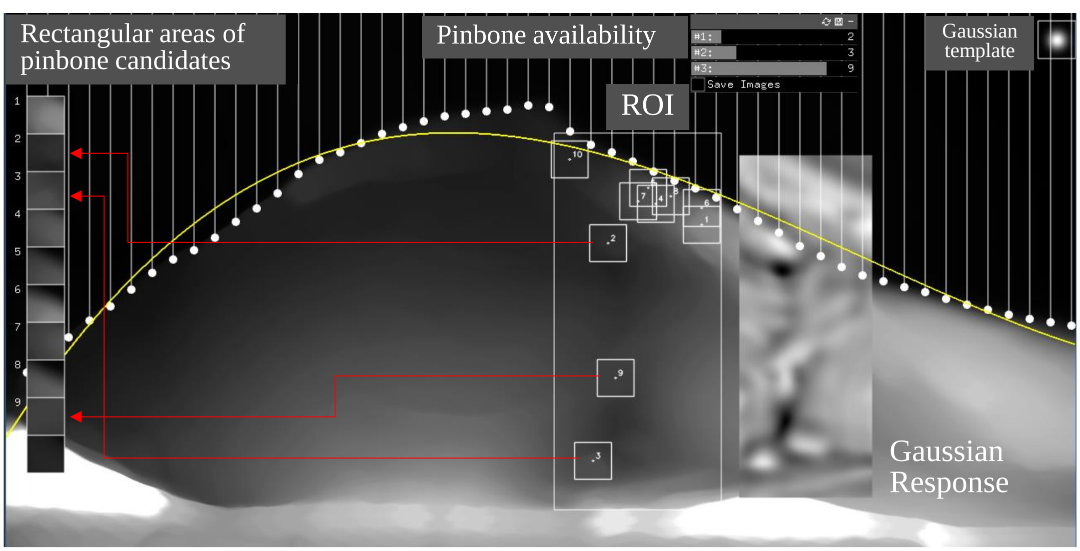
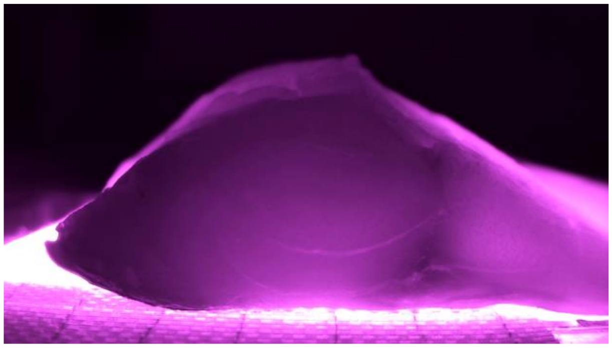
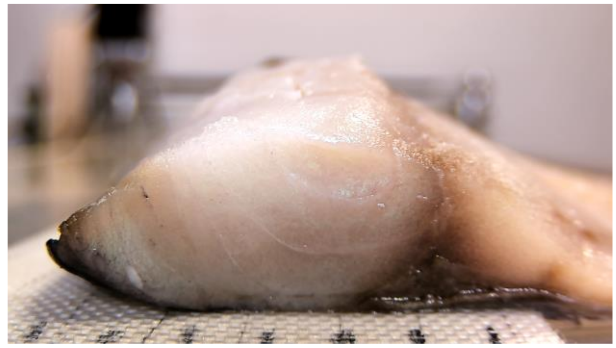


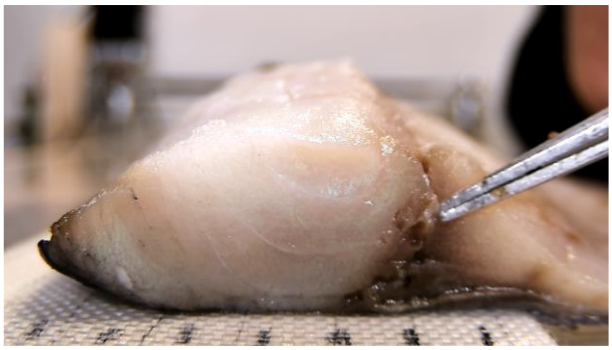
Figure 8. A GUI created to build a dataset of pinbones in the shime-saba.



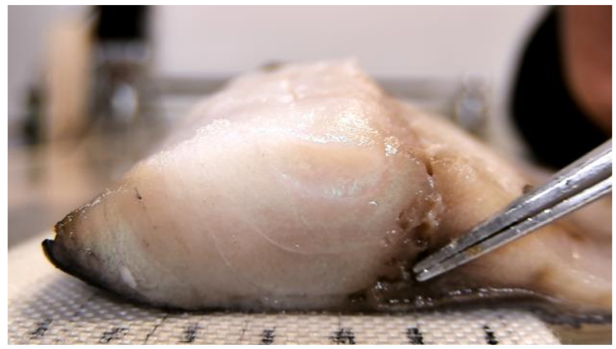
(a) NIR image.



(b) Visible spectrum.



(c) Location of the pinbone #1 in visible spectrum.



(d) Location of the pinbone #2 in visible spectrum.

Figure 9. An example of images of a fillet taken for this experiment.

and convex-up features, which are confirmed by quadratic equations. Finally, using the GUI (slider), the presence/absence label of the pinbone tips are given to these rectangles, and they are constructed into a dataset learnable by the CNN. Here, samples with pinbone tips are classified as positive and those without pinbone tips as negative in the dataset. OpenCV (opencv.org), an open-source computer vision software library, is used for this calculation.

IV. Experiments and Results

For this experiment, 95 shime-saba fillets were used. These fillets were taken from the shime-saba production process before they were packaged. Fillets with less cracks were chosen for the experiment to avoid extra NIR light influence from the cracks.

A. *Image Acquisition*

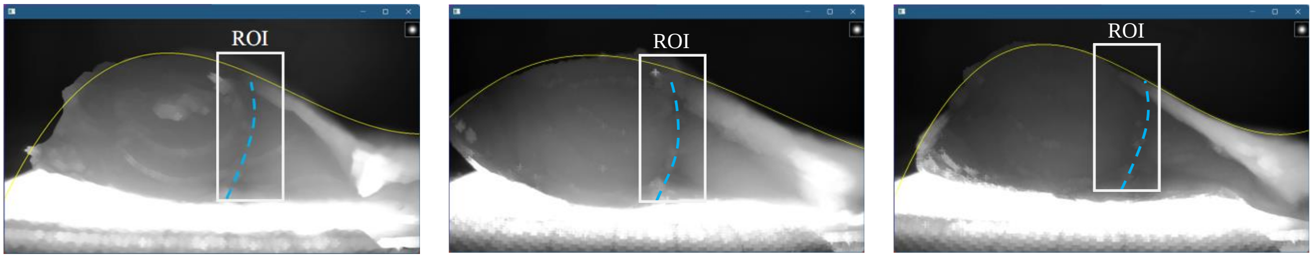
The fillets are photographed in the order of NIR and visible spectrum, and then the pinbones are located with tweezers and the scene is photographed as well. For each fillet, the images are taken as shown in Figure 9, facilitating easy generation of the positive images in the dataset that contains pinbones. From the 95 fillets of shime-saba photographed in this study, 250 locations of pinbones could be identified manually with tweezers. This means that there are around two to three pinbones in each fillet.

B. *Region of Interest (ROI)*

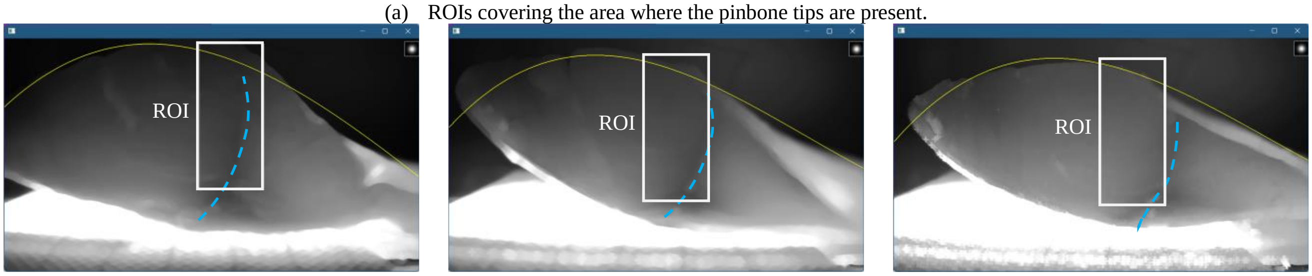
The size of the ROIs was fixed at 200 x 400 pixels and located at 175 pixels away from the top of the approximated curve of the fillet. Figure 10 shows the results of some typical ROIs. The blue dotted lines indicate the potential location of pin bones. The ROIs were determined for 95 fillets of shime-saba, with 78 ROIs covering the area where the pinbone tips are present. In addition, 14 ROIs partially covered the area where the pinbone tips are present. Only three ROIs did not correctly cover the pinbone tips. As the side of the fillet floats off the conveyor belt, the ROI falls off the pinbone positions. In this study, ROIs that did not properly cover the pinbone were manually transformed to cover the area where the pinbone was present.

C. *Ten Candidates for Pinbone Tips*

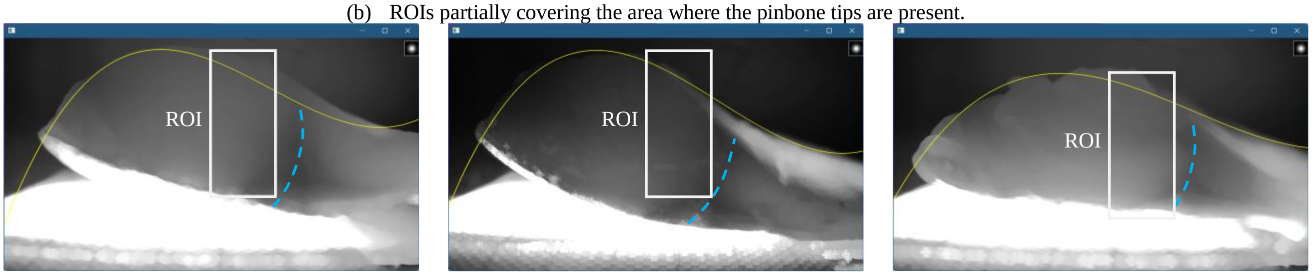
From each fillet, ten rectangular areas where pinbones potentially exist were selected in order of their convexity calculated by Equation (2). These rectangular areas were labeled for the presence or absence of pinbone tips by comparing them to locations indicated by the tweezers in the visible spectrum image of the fillet as shown in Figure 9. The top ten candidate rectangular areas were obtained from 95 fillets, for a total of 950 rectangular areas. Of those, 225 pinbones could be identified, but the remaining 25 could not. Extracting the top ten pinbone tip candidates for each fillet means that 90% of the pinbone tips can be located. However, since only a maximum of three pinbone tips are present in the cross-section of each fillet, the ten candidates must be further narrowed down. Finally, a binary classification dataset was constructed with 225 rectangular areas with confirmed pinbone tips as positive and the remaining 725 rectangular areas as negative samples.



(a) ROIs covering the area where the pinbone tips are present.



(b) ROIs partially covering the area where the pinbone tips are present.



(c) ROIs does not cover the area where the pinbone tips are present.

Figure 10. ROIs automatically identified by this study.

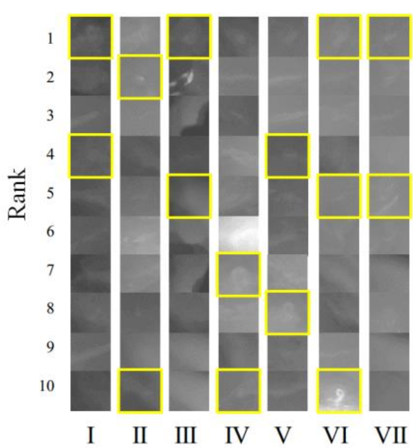


Figure 11. Rectangular areas from seven fillets (I~VII)

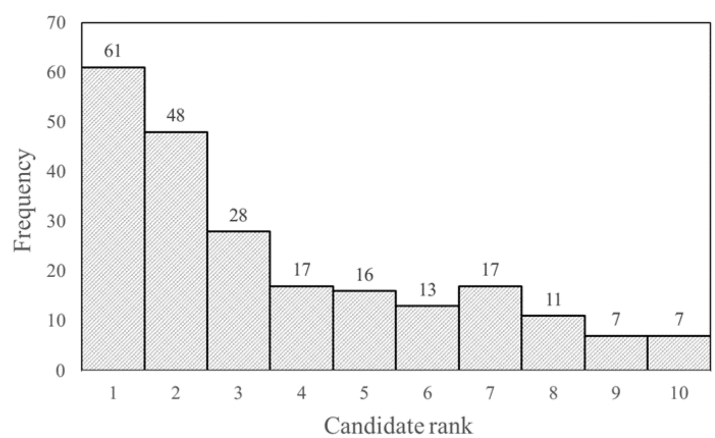


Figure 12. The relationship between rank and pinbones.

Figure 11 shows ten candidate rectangular areas extracted from seven fillets (I - VII). Yellow boxes indicate the presence of pinbone tips within the areas. Overall, the relationship between the rank of 10 candidate areas and the number of pinbones present is shown in Figure 12. Here, a higher rank can be interpreted as the presence of more pinbone tips. In other words, the presence of pinbone tips suggests that they can be found in the NIR image of the fillet where the convexity is high.

D. Determination of Pinbone Tip Using CNN

Using the previously described binary classification dataset, we trained the CNN as shown in Figure 7. About 80% (760 rectangular areas) were randomly selected for training and 20% (190 rectangular areas) for validation. Here, the batch size was set to 32, the epoch to 100, and Adam was used as the optimizer. The cost function, training error, and validation error of the CNN measured after each epoch are

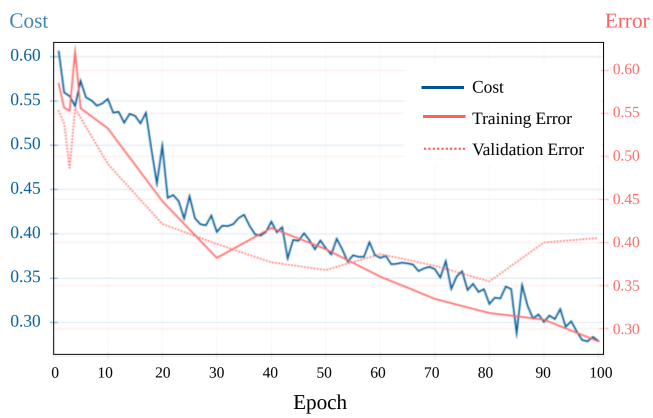


Figure 13. Learning curve of the CNN in this study.

TABLE I. CONFUSION MATRIX

		Predicted values	
		Negative	**Positive**
Real values	**Negative**	138	14
	Positive	15	25

Accuracy	0.849	**Recall**	0.625
Precision	0.641	**F-Measures**	0.633

shown in Figure 13. Up to the 80th epoch, the validation error decreases but begins to increase again. Therefore, at the 80th epoch, the model weights were outputted since the loss is low and stable. Table I shows the confusion matrix of the learned CNN model. Accuracy was good at 84.9%, but precision, recall, and F-Measures were relatively low at just over 60%. The reason can be attributed to the small sample size of the dataset and to positive samples being only about 30% of the total number of negative samples. The results of this study, however, are encouraging as a first attempt in this effort, and we believe that the results can be improved further by increasing samples in the dataset and by improving the method of determining the ROI and the design of the CNN.

V. DISCUSSION

The ROI of this study, which limits the analysis area for efficient pinbone tip detection, is expected to not only reduce the computational cost but also reduce misdetections. However, identifying the boundary points of the fillets by edge intensity and approximating those points with a cubic curve is susceptible to influence by noise. In addition, when multiple fillets are side-by-side, calculation of the cubic curves according to each fillet becomes more complicated.

For future development, we experimented with the use of CNN-based semantic segmentation to estimate the boundaries of fillets as shown in Figure 14. There are two main parts: a contraction pass consisting of a convolution layer unit and an expansion pass consisting of a deconvolution layer unit. Each convolution is followed by batch normalization and Rectified Linear Unit (ReLU). Input data consisted of NIR images of 95 fillets of shime-saba fillet used in our experiment and manually annotated fillet shapes.

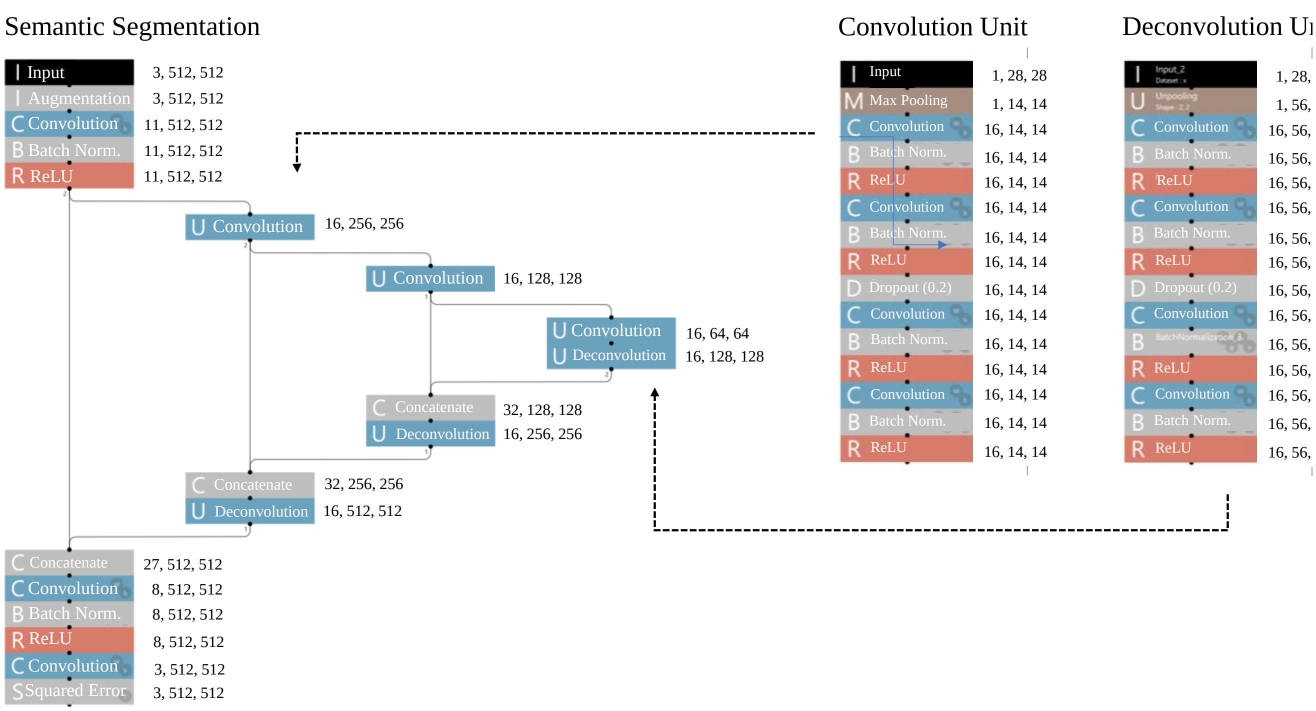
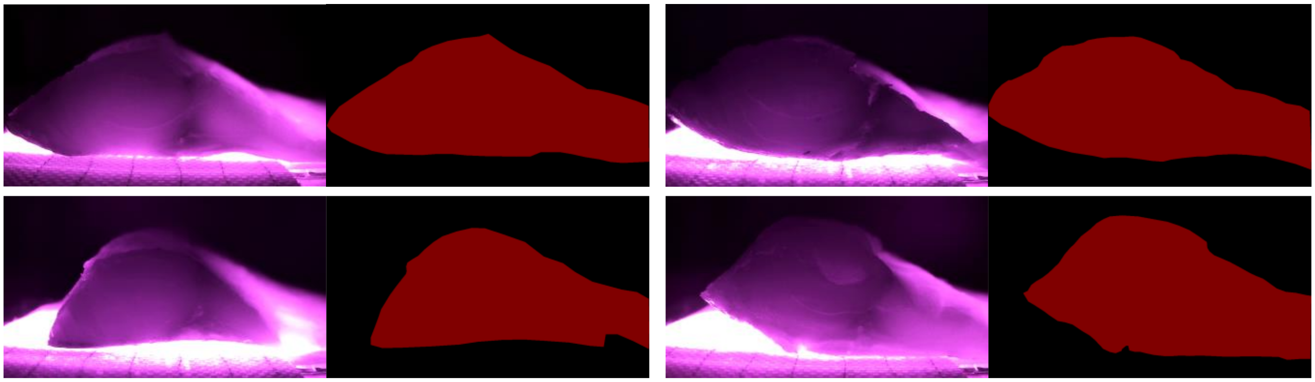
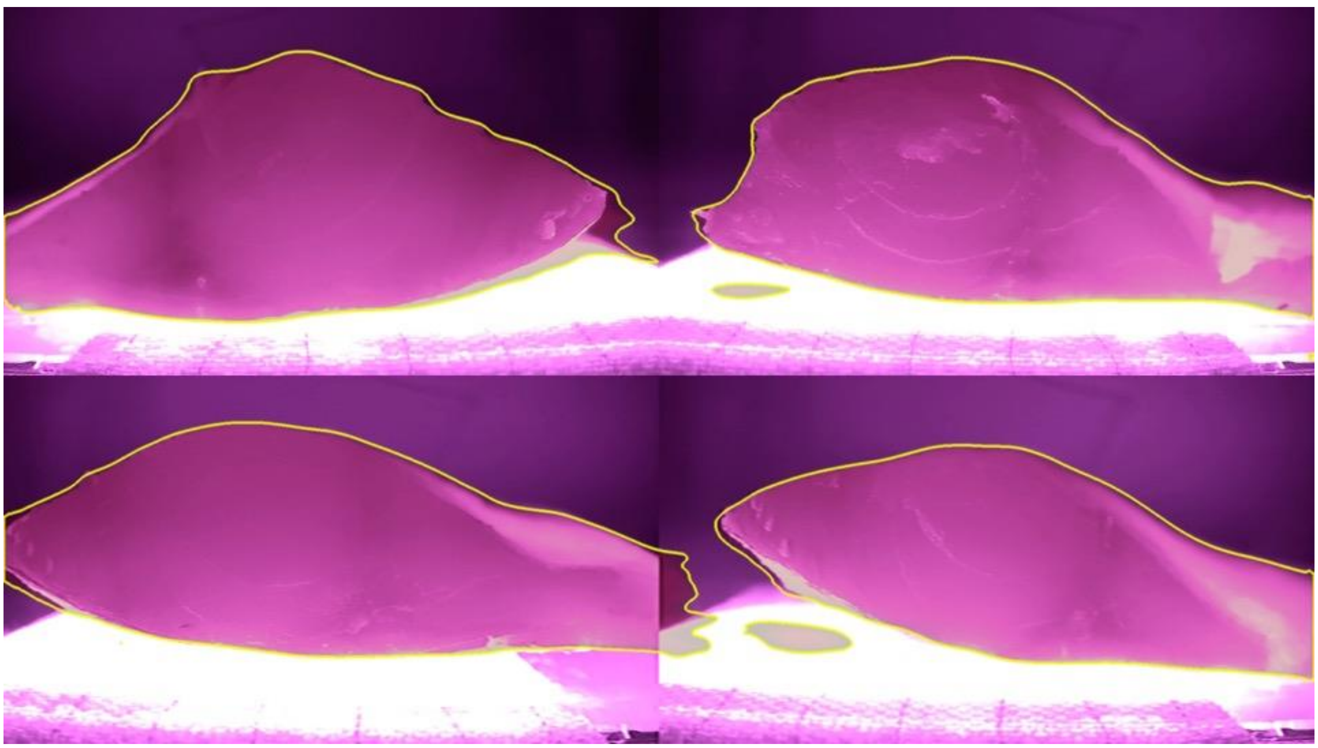


Figure 14. Neural network of the semantic segmentation for this study



(a) Manually annotated shime-saba fillets.



(b) Fillet shapes detected using the CNN-based semantic segmentation

Figure 15. Manually annotated shime-saba fillets and fillet shapes detected using the CNN-based semantic segmentation.

LabelMe, a labeling and annotation tool, was used for annotation [13].

Figure 15(a) shows shime-saba fillets manually annotated using LabelMe (red areas). Since the boundary is not clear in the area of fillet touching the conveyor belt, the darker area toward the fillet was treated as the boundary. To evaluate the derived model of semantic segmentation, we merged two fillet images horizontally and inferred the boundaries of each with the model. As shown in Figure 15(b), the two fillets can be separated, and the boundaries of each fillet (yellow lines) extracted are acceptable. The result is expected to enable the identification of the thickest part of the shime-saba fillet, which will facilitate the identification of areas of the pinbone tips.

VI. CONCLUSION

In this study, an image sensing system for detecting the pinbone tips of shime-saba was developed. The two-step processes of selecting local convex-up areas by mathematical quadratic surfaces and determining pinbone-containing areas by the Convolution Neural Network enable pinbone locations to be automatically identified. Pinbone detection accuracy was 84.9%, while Precision, Recall, and F-Measures were relatively low at just over 60%. As a first attempt, this result is acceptable. Further improvement in results can be expected by increasing the number of samples in the data set.

Since the area where pinbones are located is known to be in and around the middle of the fillet, the proposed cubic curve based on the edge information indicates that these areas can be estimated. For a better method of obtaining the area, we found that automatic extraction of the fillet shape by semantic segmentation can also be used. This method enables simultaneous detection of pinbone tips from multiple fillets.

Future experiments will include the implementation of a deboning robot that will remove the detected pinbone tips. The results will be presented in our forthcoming paper.

Acknowledgment

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Developing a Formal Model of Conversational Agent

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***Abstract*—Our model of conversational agent is based on the analysis of human-human telemarketing calls. We study negotiations where two participants are presenting arguments for and against of doing an action. The choice of an argument depends, on one hand, on the beliefs of the dialogue participant about the positive and negative aspects of the action and the needed resources, and on the other hand, on the result of reasoning affected by these beliefs. The dialogue initiator is using a partner model—the hypothetical beliefs of the partner who is aimed to do the action. At the same time, the partner operates with own beliefs. Both the models have to be upgraded during a dialogue. The notion of a communicative strategy is included in the model as an algorithm used by a dialogue participant for achieving his or her communicative goal. A limited version of the model is implemented on the computer. The computer attempts to influence the reasoning of the user by its arguments in order to convince the user to make the positive decision about the proposed action.**

Keywords—reasoning; beliefs; communicative strategy; negotiation; argument; conversational agent.

I. INTRODUCTION

This article is an extended version of the conference paper [1]. Our aim is to develop a model of conversational agent that interacts with a user in a natural language and carries out negotiations.

Negotiation is a form of interaction in which a group of agents, with a desire to cooperate but with potentially conflicting interests try to come to a mutually acceptable division of scarce resources [2]. Negotiation is simultaneously a linguistic and a reasoning problem, in which intent must be formulated and then verbally realized. A variety of agents have been created to negotiate with people within a large spectrum of settings including the number of parties, the number of interactions, and the number of issues to be negotiated [3]. Negotiation dialogues contain both cooperative and adversarial elements, and their modelling require agents to understand, plan, and generate utterances to achieve their goals [3][4].

We start with the analysis of human-human negotiation dialogues aiming to model the reasoning processes, which people go through when pursuing their communicative goals and coming to a decision.

The remainder of the paper is organized as follows. Section 2 describes related work. In Section 3, we analyze a kind of human-human negotiation dialogues—telemarketing calls, in order to explain how do people reason and argue when negotiating about doing an action. In Section 4, we introduce our model of conversational agent that takes into account the results of the analysis of human-human negotiations, and an implementation—a simple dialogue system (DS). Section 5 discusses the model and the DS. In Section 6, we draw conclusions and plan future work.

II. RELATED WORK

A conversational agent, or DS, is a computer system intended to interact with a human using text, speech, graphics, gestures and other modes for communication. It will have both dialogue modelling and dialogue management components [5]. A dialogue manager is a component of a DS that controls the conversation. The dialogue manager reads the input modalities, updates the current state of the dialogue, decides what to do next, and generates output [6]. Four kinds of dialogue management architectures are most common—plan-based, finite-state, frame-based, and information-state [7].

One of the earliest models of conversational agent is based on the use of artificial intelligence *planning* techniques. Using plans to generate and interpret sentences require the models of beliefs, desires, and intentions (BDI) [4][5]. Plan-based approaches, though complex and difficult to embed in practical dialogue systems, are seen as more amenable to flexible dialogue behavior [7].

The simplest dialogue manager architecture, used in many practical implementations, is a *finite-state* manager. The states correspond to questions that the dialogue manager asks the user, and the arcs correspond to actions to take depending on what the user responds. Such a system completely controls the conversation with the user. It asks the user a series of questions, ignoring or misinterpreting anything the user says that is not a direct answer to the system's question, and then going on to the next question [7].

Frame-based dialogue managers ask the user questions to fill slots in a frame until there is enough information to perform a data base query, and then return the result to the user. If the user answers more than one question at a time, the system has to fill in these slots and then remember not to ask the user the associated questions for the slots. In this way, the user can also guide the dialogue [5].

More advanced architecture for dialogue management, which allows for sophisticated components is the *information-state* architecture [5][7]. An information-state approach combines the other approaches, using the advantages of each. An information state includes beliefs, assumptions, expectations, goals, preferences and other attitudes of a dialogue participant that may influence the participant's interpretation and generation of communicative behavior. The functions of the dialogue manager can be formalized in terms of information state update [8]. Update and selection rules provide a more transparent, declarative representation of system behavior.

Rahwan et al. [9] discuss three approaches to automated negotiation—game-theoretic, heuristic-based and argumentation-based.

A dialogue game is a rule-based structure for conversation where arguments are exchanged between two participants reasoning together on a turn-taking basis aimed at a collective goal [10]. *Heuristic methods* offer approximations to the decisions made by participants. Agents exchange proposals (i.e., potential agreements or potential deals). Both game-theoretic and heuristic approaches assume that agents' preferences are fixed. One agent cannot directly influence another agent's preferences, or any of its internal mental attitudes (beliefs, desires, goals, etc.) that generate its preference model. A rational agent only modifies its preferences if it receives new information.

Attitudes are relatively enduring, affectively colored beliefs, preferences, and predispositions towards objects or persons [11]. Attitude is a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor. Attitude change can mediate the impact of some influence treatment on behavioral compliance [12].

Argumentation-based approaches to negotiation allow agents to 'argue' about their beliefs and other mental attitudes during the negotiation process. Argumentation-based negotiation is the process of decision-making through the exchange of arguments [13].

Hadjinikolis et al. [14] provide an argumentation-based framework for persuasion dialogues, using a logical conception of arguments, that an agent may undertake in a dialogue game, based on its model of its opponents. In negotiation, an argument can be considered as a piece of information that may allow an agent to (a) justify its negotiation state; or (b) influence another agent's negotiation state. Amgoud and Cayrol define an argument as a pair (H, h) where (i) H is a consistent subset of the knowledge base, (ii) H implies h, (iii) H is minimal, so that no subset of H satisfying both (i) and (ii) exists. H is called the support and h the conclusion of the argument [15].

Automated negotiation agents capable of negotiating efficiently with people must rely on a good opponent modelling component to model their counterpart, adapt their behavior to their partner, influencing the partner's opinions and beliefs [16]. NegoChat is the first negotiation agent successfully developed to use a natural chat interface while considering its impact on the agent's negotiation strategy [3]. A virtual human negotiating with a human helps people learn negotiation skills. For virtual agents, the expression of attitudes in groups is a key element to improve the social believability of the virtual worlds that they populate as well as the user's experience, for example in entertainment or training applications [17][18][19]. Argumentation systems can be beneficial for students.

Computers that negotiate on our behalf hold great promise for the future in emerging application domains such as the smart grid and the Internet of Things. An interesting and useful kind of DSs are embodied conversational agents [17][20][21].

III. Analysis of Human-Human Negotiations

Our further aim is to implement a DS, which interacts with a user in a natural language (Estonian) and carries out negotiations like a human does. For that, we are studying human-human negotiations using the Estonian dialogue corpus [22]. All the dialogues in the corpus are recorded in authentic situations and then transliterated by using the transcription of Conversation Analysis [23]. A sub-corpus of telemarketing calls is chosen for the current study. In the dialogues, two official persons are communicating—a sales clerk of an educational company, he is the initiator of a call, and a manager or a personnel officer of another institution—she is here a customer.

The educational company offers training courses (management, sale, etc.), which can be useful for the employees of the customer's institution. The communicative goal of a sales clerk is to convince the customer to decide to order a course.

Several typical phases can be differentiated in telemarketing negotiations [24]: (1) preparing, (2) opening, (3) mapping the customer, (4) argumentation, (5) achieving a decision, (6) following activities. The first (1) and the last (6) phases take place outside of actual negotiation.

Phase 1 is carried out by a sales clerk alone when he is planning his very first call to a pre-selected customer. The clerk, by using different open sources, tries to collect information about the customer's institution—its background, financial situation, the number of employees, etc., in order to be ready to propose and argue for a suitable course. The last phase (6) will be initiated by a sales clerk after the customer has already passed a course. Then the clerk again calls to the customer asking her feedback. Still, our sub-corpus does not include such calls. Therefore, it is possible to recognise only the phases 2 to 5 in the dialogues of our sub-corpus.

As a rule, several calls are needed before a customer makes her decision about the offered course. The decision can be positive (to take the course) or negative (to reject the clerk's proposal). However, no decision is mostly made regarding the courses during a call—the calls usually end with an agreement to continue the negotiation after some time. The reason is that all the telemarketing calls in our corpus belong to the beginning stage of negotiations.

The most important phase of negotiation is *argumentation*. A sales clerk (A) presents different arguments that take into account the actual needs of the customer (B) explained by him (A) before or during the call. A tries to bring out the factors that are essential for the customer, in order to convince her to make a positive decision (Example 1). If B accepts these factors then A will demonstrate how the proposed course will solve B's assumed problems. In an ideal case, the customer will agree with the proof offered by the clerk and she will decide to take the course.

The behaviour of sales clerks and customers is different when they are arguing for/against a course. A sales clerk when having the initiative provides his arguments for taking the course either asserting something (then a customer typically accepts the assertion, Example 1).

Example 1 (transcription of Conversation Analysis is used in the examples)

A: /---/(1.0) .hh sest loomu`likult et=ee `töökogemuste kaudu: õpib ka: alati aga .hh a `sageli ongi just `see (0.5) mt ee `kursused pakuvad sellise `võimaluse kus saab siis `teiste .hh oma hh `ala `spetsia`listidega samuti `kokku=ja `rääkida nendest `ühistest prob`leemidest ja samas siis ka .hh ee `mõtteid ja `ideid ee hh ee=`Tiritamme poolt sinna `juurde.

`because, of course, one can learn from experience but frequently training courses make it possible to meet other specialists in the field and discuss common problems; additional thoughts and ideas come from Tiritamm` argument

`(.)`

B: £ `jah?

`yes` accept

A customer, to the contrary, does not accept assertions/arguments of a sales clerk when arguing against taking a course (Example 2).

Example 2

/---/ *B*: aga jah ei mul on see läbi ´vaadatud=ja (.) ´kahjuks ma pean ütlema=et (.) et ´teie (.) seda meile (.) ´ei suuda ´õpetada (.) mida (.)´mina: (.) tahan.

`but I have looked through your catalogue of courses and unfortunately, I have to say that you can't teach what is needed for us` counter argument

/---/

A: .h ja mida kon´kreetselt=ee ´teie tahate.

`and what do you want` question

(0.8) mida te ´silmas ´peate. `what do you have in view` question

B: noo (0.2) ´meie (.) äri´tegevus on (.) ´ehitamine.

`well, our business is house-building` answer

/---/

A: nüüd kas (0.2) näiteks (0.5) ´lepingute ´saamisel (0.5) mt ee ´tegelete te ka: läbi´rääkimistega.

`well, do you need to carry out negotiations in order to achieve agreements` question

B: noo ikka.

`yes, of course` answer

(0.8)

A: mt et see=on ka üks ´valdkond mida me: (0.2) ´käsitleme.

`but that is one of our fields, which we cover` argument

The argumentation continues in a similar way. *A* attempts to convince *B* preparing his new arguments by questions. Either *A* constructs his arguments during the conversation or he chooses suitable arguments from a previously completed set of possible arguments collected in discussions with other customers.

In Example 3, the customer takes over the initiative and explains that no courses are needed because her experience is unique.

Example 3

B: /---/ me ´müüme eksklu´siivset ´kodu´mööblit.

`we are selling exclusive home furniture.`

/---/

noo siis ´see kauba´märk ka juba ütleb iseendast se=on ´täpselt sama´moodi nagu on Mer´seedes=´Pens ja ´Jaaguar.

`this trademark speaks for itself, like Mercedes Benz and Jaguar.`

[eksole]

`is it not?` counter argument

A: [jaa.]

`yes.`

seda ´küll?

`it is.` accept

A sales clerk always accepts the counter arguments presented by a customer but he also brings out his own arguments for taking the course and tries to take over the initiative. The participants communicate cooperatively in the majority of the analyzed dialogues. The customer similarly can ask questions like the sales clerk does but her aim is rather to get more information about the course(s) than to dispute.

When modelling negotiation, a good way seems to follow the sales clerks' strategy: try to take and hold the initiative and propose 'hard' arguments for the strived action, i.e., the statements that do not provoke the partner's rejection but accept. In order to have such arguments at disposal, it is necessary to know as possible more about the partner in relation to the goal action. That is the reason why mapping (i.e., explanation of the customer's needs) is a necessary phase (3) in our analyzed telemarketing calls.

In summary, telemarketing calls turn out to be good examples of argument-based negotiations.

IV. Modelling Conversational Agent

Our model of conversational agent is motivated by the results of the analysis of human-human negotiations. Let us consider negotiation between two (human or artificial) participants *A* and *B* where *A* is the initiator. Let *A*'s communicative goal be to bring *B* to the decision to do an action *D*. When convincing *B*, he is using a partner model (an image of the communication partner) that gives him grounds to believe that *B* will agree to do the action. *A* starts the dialogue by proposing *B* to do *D*. If *B*, after her reasoning, refuses, then *A* must influence her in the following negotiation, continuously correcting his partner model and trying to guess in which reasoning step *B* reached her negative decision. In this way a dialogue—a sequence of utterances will be generated together by *A* and *B*.

A. Reasoning Model

The initial version of our reasoning model is introduced in [24]. In general, it follows the ideas realized in the BDI model [25][4][5]. The reasoning process of a subject about doing an action *D* consists of steps where the resources, positive and negative aspects of *D* will be weighed. A communication partner can take part in this process only implicitly by presenting arguments to stress the positive aspects of *D* and downgrade the negative ones.

Our reasoning model includes two parts—(1) a model of (human) motivational sphere that represents the beliefs of a reasoning subject in relation to the aspects of the action under consideration, and (2) reasoning procedures.

1) Model of Motivational Sphere

We represent the model of *motivational sphere* of a communication participant as a vector with (here: numerical) coordinates that express the beliefs of the participant in relation to different aspects of the action *D*:

$$\mathbf{w}_D = (w(resources_D), w(pleasant_D), w(unpleasant_D), w(useful_D), w(harmful_D), w(obligatory_D), w(prohibited_D), w(punishment\text{-}do_D), w(punishment\text{-}not_D)).$$

The value of $w(resources_D)$ is 1 if the reasoning subject has all the resources needed for doing *D*, and 0 if some of them are missing. The value of $w(obligatory_D)$ or $w(prohibited_D)$ is 1 if the action is obligatory or, respectively, prohibited for the subject (otherwise 0). The values of the other coordinates can be numbers on the scale from 0 to 10—$w(pleasant_D)$, $w(unpleasant_D)$, etc, indicate the values of the pleasantness, unpleasantness, etc. of *D* or its consequences; $w(punishment\text{-}do_D)$ is the punishment for doing a prohibited action and $w(punishment\text{-}not_D)$—the punishment for not doing an obligatory action.

2) Reasoning Procedures

The reasoning itself depends on the *determinant* which triggers it. With respect to the used (intuitive) theory, there are three kinds of determinants that can cause humans to reason about an action *D*: wish, need and obligation [26]. Therefore, three different prototypical *reasoning procedures* can be described—WISH, NEEDED, and MUST. Every procedure consists of steps passed by a reasoning subject and it finishes with a decision—do *D* or not. When reasoning, the subject considers his/her resources as well as different positive and negative aspects of doing *D*. If the positive aspects (pleasantness, usefulness, etc.) weigh more than negative (unpleasantness, harmfulness, etc.) then the decision will be "do *D*" otherwise "do not do *D*". The reasoning subject checks primarily his/her wish, thereafter the need and then the obligation and he/she triggers the corresponding reasoning procedures. If no one procedure returns the decision "do *D*" then the reasoning ends with the decision "do not do *D*".

In Figures 1 and 2, we present two reasoning procedures that will be used in the following examples—WISH triggered by the wish of the reasoning subject to do the action *D* (i.e., doing the action is more pleasant than unpleasant for the subject), and NEEDED triggered by the need of the reasoning subject to do the action *D* (i.e., doing the action is more useful than harmful for the subject). The procedures are presented as step-form algorithms. We do not more indicate the action *D*.

Presumption: *w(pleasant) ≥ w(unpleasant).*
1) *Is w(resources) = 1? If not then 11.*
2) *Is w(pleasant) > w(unpleasant) + w(harmful)?* If not then go to 6.
3) *Is w(prohibited) = 1?* If not then go to 10.
4) *Is w(pleasant) > w(unpleasant) + w(harmful) + w(punishment_D)?* If yes then go to 10.
5) *Is w(pleasant) + w(useful) > w(unpleasant)+w(harmful) + w(punishment_D)?* If yes then go to 10 else 11.
6) *Is w(pleasant) + w(useful) ≤ w(unpleasant) + w(harmful)?* If not then go to 9.
7) *Is w(obligatory) = 1?* If not then go to 11.
8) *Is w(pleasant) + w(useful) + w(punishment_not) > w(unpleasant) + w(harmful)?* If yes then go to 10 else 11.
9) *Is w(prohibited) = 1?* If yes then go to 5 else 10.
10) Decide: to do D. End.
11) Decide: not to do D.

Figure 1. Reasoning procedure WISH.

Presumption: *w(useful) ≥ w(harmful).*
1) *Is w(resources) = 1?* If not then go to 8.
2) *Is w(pleasant) > w(unpleasant)?* If not then go to 5.
3) *Is w(prohibited) = 1?* If not then go to 7.
4) *Is w(pleasant) + w(useful) > w(unpleasant) + w(harmful) + w(punishment-do)?* If yes then go to 7 else 8.
5) *Is w(obligatory) = 1?* If not then go to 8.
6) *Is w(pleasant) + w(useful) + w(punishment-not) > w(unpleasant) + w(harmful)?* If not then go to 8.
7) Decide: do D. End.
8) Decide: do not do D.

Figure 2. Reasoning procedure NEEDED.

We use two vectors $\mathbf{w}^B$ and $\mathbf{w}^{AB}$, which capture the beliefs of communication participants in relation to the action *D* under consideration. Here $\mathbf{w}^B$ is the model of motivational sphere of *B* who has to make a decision about doing *D*; the vector includes *B*'s (actual) evaluations (beliefs) of *D*'s aspects. These values are used by *B* when reasoning about doing *D*. The other vector $\mathbf{w}^{AB}$ is the partner model that includes *A*'s hypothetical beliefs concerning *B*'s beliefs in relation to the action. It is used by *A* when planning the next turns in dialogue. We suppose that *A* has some preliminary knowledge about *B* in order to compose the initial partner model before making the initial proposal.

Both the models will change as influenced by the arguments presented by both the participants in negotiation. For example, every argument presented by *A* targeting the usefulness of *D* will increase the corresponding values of w^B*(useful)* as well as w^{AB}*(useful)*.

B. Communicative Strategies and Tactics

A communicative strategy is an algorithm used by a participant for achieving his/her goal in communication [27]. The initiator *A* can realize his communicative strategy in different ways—he can entice, persuade or threaten the partner *B* to do (or respectively, not to do) *D.* We call these ways of realization of a communicative strategy *communicative tactics*. If *A*'s communicative goal is "*B* will do *D*" then by *persuading*, *A* tries to trigger *B*'s reasoning by the NEEDED-determinant (i.e., he tries to increase the usefulness of *D* for *B* as compared with its harmfulness). Respectively, when *enticing*, *A* tries to trigger *B*'s reasoning by the WISH-determinant (to increase the pleasantness) and when *threatening*, by the MUST-determinant (to increase the punishment for not doing an *obligatory D*). We call the affected aspect (respectively, usefulness, pleasantness, or punishment) the *title aspect* of the tactics. When choosing the communicative tactics, *A* believes that *B*'s reasoning triggered by this determinant, will give a positive decision in his partner model. Still, the participants can change their communicative tactics during negotiation.

- Determine the initial $\boldsymbol{w}^{AB}$ in relation to *D*
- Choose an input determinant (WISH, NEEDED, or MUST), which determines a reasoning procedure depending on $\boldsymbol{w}^{AB}$
- Choose the communicative tactics with the title aspect *a* (respectively, pleasantness, usefulness or punishment for not doing *D* if it is obligatory for *B*)
- Implement the tactics to generate a proposal to *B* to do *D*

REPEAT
Analyze *B*'s utterance
- - (1) Choose a (counter) argument depending on the aspect of *D* indicated in *B*'s utterance
- - (2) Choose argument(s) to support *a*
Update $\boldsymbol{w}^{AB}$
Run the current reasoning procedure in updated $\boldsymbol{w}^{AB}$
- - Response to *B*
IF the decision generated with the reasoning procedure matches to G^A THEN present the chosen argument(s) to *B* (- - *A* can optionally present both (1) and (2), OR only (2))
Change the communicative tactics? IF yes THEN choose the new tactics (with new *a*)
UNTIL *B* agrees (G^A achieved), OR *B* postpones the decision (G^A not yet achieved), OR *A* decides to abandon G^A, OR *A* does not have unused tactics and/or unused arguments (G^A not achieved)

Figure 3. Communicative strategy of the initiator *A* (G^A =*B will do D).*

Let us present two communicative strategies in Figures 3 and 4, respectively, for *A* and for *B*. It is assumed here that their initial communicative goals are similar—that *B* decides to do *D*. Still, there can be some obstacles for *B* (resources are missing, or *D* is prohibited and its doing will be punished, etc.). In negotiation, *A* has to demonstrate how the obstacles can be crossed over.

Both *A* and *B* can indicate that the finishing conditions are fulfilled: (1) the communicative goal is already achieved, (2) give up regardless of having new arguments or counter arguments, (3) there are no more arguments to continue the fixed tactics but no new tactics will be chosen regardless of having some tactics not implemented so far, (4) all the tactics are already implemented and all the possible arguments are used without achieving the communicative goal. We assume here that the communicative tactics and arguments can be used only once.

- Determine the initial $\boldsymbol{w}^B$ in relation to *D*
- Choose an input determinant (WISH, NEEDED, or MUST) which determines a reasoning procedure depending on $\boldsymbol{w}^B$

REPEAT
Analyze *A*'s utterance
CASE *A*'s utterance OF
resources: increase resources
pleasantness: increase pleasantness
unpleasantness: decrease unpleasantness
usefulness: increase usefulness
harmfulness: decrease harmfulness
punishment for not doing an obligatory *D*: increase punishment
punishment for doing a prohibited *D*: decrease punishment
END CASE
Update $\boldsymbol{w}^B$
Change the reasoning procedure? IF yes THEN choose a new procedure
Run the current reasoning procedure in updated $\boldsymbol{w}^B$
Choose and present a new (counter) argument depending on the result of the reasoning procedure
UNTIL *B*'s current reasoning procedure gives the decision, which matches to G^B in the current $\boldsymbol{w}^B$ (*A* and *B* achieved their joint goal), OR whether *A* or *B* abandoned their joint goal, OR *B* postpones the decision (*A* and *B* did not yet achieve their joint goal).

Figure 4. Communicative strategy of the partner *B* (G^B= G^A=*B will do D).*

If *A or B* gives up then the communicative goal will be not achieved. If *B* postpones her decision at the end of dialogue then there are neither winners nor losers.

Questions can be asked by participants in order to make choices among different propositions that can be used in argumentation.

C. Information States in Negotiation Process

If both *A* and *B* are conversational agents then let us assume the availability of following knowledge [27]:

1) a set *G* of communicative goals where both participants choose their initial goals (G^A and G^B, respectively). In our case, $G^A = G^B$= "*B* decides to do *D*"

2) a set *S* of communicative strategies of the participants. A communicative strategy is an algorithm used by a participant for achieving his/her communicative goal. This algorithm determines the activity of the participant at each communicative step

3) a set *T* of communicative tactics, i.e., methods of influencing the partner when applying a communicative strategy. For example, *A* can entice, persuade, or threaten *B* in order to achieve the goal G^A, i.e., *A* attempts to demonstrate that achieving this goal is, accordingly, more pleasant than unpleasant, more useful than harmful, or obligatory for *B*

4) a set *R* of reasoning procedures, which are used by participants when reasoning (here: about doing an action *D*). A reasoning procedure is an algorithm that returns the positive or negative decision about the reasoning object (the action *D*)

5) a set *P* of participant models, i.e., a participant's depictions of the beliefs of himself/herself and his/her partner in relation to the reasoning object: $P = \{P^A(A), P^A(B), P^B(A), P^B(B)\}$

6) a set of world knowledge

7) a set of linguistic knowledge.

A conversational agent passes several *information states* during interaction starting from the initial state and going to every next state by applying *update rules*. Information states represent cumulative additions from previous actions in the dialogue, motivating future actions. There are two parts of an information state of a conversational agent [8] —private (information accessible only for the agent) and shared (accessible for both participants).

The private part of an information state of the conversational agent *A* (dialogue initiator) consists of the following information: (a) current model of the partner *B*, (b) communicative tactics t_i^A, which *A* has chosen for influencing *B*, (c) the reasoning model r_j, which *A* is trying to trigger in *B* and bring it to the positive decision (it is determined by the chosen tactics, e.g., when persuading, *A* tries to increase *B*'s need to do *D*), (d) a set of dialogue acts $DA=\{d_1^A, d_2^A, \ldots, d_n^A\}$, which *A* can use, (e) a set of utterances for increasing or decreasing the values of *B*'s attitudes in relation to *D* (arguments for/against of doing *D*) $U=\{u_{i1}^A, u_{i2}^A, \ldots, u_{iki}^A\}$.

The shared part of an information state contains (a) a set of reasoning models $R=\{r_1,\ldots,r_k\}$, (b) a set of communicative tactics $T=\{t_1, t_2, \ldots, t_p\}$, and (c) dialogue history $p_1{:}u_1[d_1], p_2{:}u_2[d_2],\ldots, p_i{:}u_i[d_i]$ where $p_1=A; p_2$, etc. are *A* or *B*.

A stack is used keeping (sub-)goals under consideration. In every information state, the stack contains an aspect of *D* under consideration (e.g., when *A* is persuading *B* then the usefulness is on the top).

Two categories of *update rules* are at disposal of conversational agent for moving from current information state into the next one: (1) for interpreting the partner's turns and (2) for generating its own turns. For example, there are the following rules for the initiator *A* in order to *generate* its turns:

1) for the case if the title aspect of the used tactics is located on top of the goal stack (e.g., for the tactics of persuasion, the title aspect is usefulness)
2) for the case if another aspect is located over the title aspect of the used tactics (e.g., if *A* is trying to increase the usefulness of *D* for *B* but *B* argues for unpleasantness, then the unpleasantness lies over the usefulness)
3) for the case if there are no more utterances for continuing the current tactics (and new tactics should be chosen if possible)
4) for the case if *A* has to abandon its goal
5) for the case if *B* has made the positive decision and therefore, *A* has reached the goal.

Special rules exist for updating the initial information state.

D. Implementation

A simple dialogue system is implemented that carries out negotiations with a user in a natural language about doing an action [27]. The participants can have different initial goals: e.g., the initiator (either DS or a user) tries to achieve the decision of the partner to do the action but the partner's goal can be opposite. DS interacts with a user using texts in a natural language. There are two work modes. In one mode, the computer is playing *A*'s and in the other—*B*'s role.

Both *A* and *B* have access to a common set of reasoning procedures. They also use fixed sets of dialogue acts and the corresponding utterances in a natural language which are pre-classified semantically, e.g., the set $P_{missing\_resources}$ for indicating that some resources for doing a certain action *D* are missing (e.g., *I don't have proper dresses*, see Example 4), $P_{increasing\_resources}$ for indicating that there exist resources (e.g., *The company will cover all your expenses*), $P_{increasing\_usefulness}$ for stressing the usefulness of *D* (e.g., *You can be useful for the company*), etc. Therefore, no linguistic analysis or generation will be made during a dialogue in current implementation. The utterances will be accidentally chosen by conversational agent from the suitable semantic classes (in our implementation, every utterance can be used only once). However, these restrictions will bring along that the generated dialogues are not quite coherent.

If *A*'s goal is "*B* will do *D*" then *A*, starting interaction, generates, by using his knowledge, a partner model $\boldsymbol{w}^{AB}$ and determines the communicative tactics *T*, which he will use (e.g., persuasion), i.e., he accordingly fixes the reasoning procedure *R*, which he will try to trigger in *B*'s mind (e.g., NEEDED). *B* (if being another conversational agent) has her own model $\boldsymbol{w}^B$ (which exact values *A* does not know). *B* in her turn determines a reasoning procedure R^B that she will use in order to make a decision about doing *D*, and her communicative tactics T^B.

When attempting to direct *B*'s reasoning to the positive decision (do *D*), *A* presents several arguments stressing the positive and downgrading the negative aspects of *D*. Preparing an argument, *A* triggers the current reasoning procedure in his partner model $\boldsymbol{w}^{AB}$, in order to be sure that the reasoning will give the positive decision. *B* can use the same or a different reasoning procedure triggering it in the model of herself $\boldsymbol{w}^B$. After the changes made by both the participants in the two models during a dialogue, the models will approach each to other but, in general, do not equalise. Although, the results of reasoning in both models can be (or not be) equal.

1) Upgrading the model $\boldsymbol{w}^{AB}$

Let us consider a dialogue with our DS (Example 4). Here *A* is conversational agent playing the role of the boss of a company and *B* is the user playing the role of an employee of the company who is at the same time studying at the university. *A* presents arguments for doing *D* by *B* (*D*=travel to *N.* to conclude a contract). He succeeds to decline *B*'s counter arguments and convince *B* to accept its goal.

Example 4

```
1.A: The company offers you a trip to N. Our company needs to conclude a contract there.
2.B: I don't have proper dresses.
3.A: The company will pay your executive expenses. You can be useful for the company.
4.B: I can have some problems at my university.
5.A: It's all right–your examinations period will be extended. The company will evaluate your contribution.
6.B: OK, I'll do it.
7.A: I am glad.
```

Let us examine how the partner model is used in the dialogue. *A* will implement the tactics of *persuasion* and generates a partner model, let it be

$\boldsymbol{w}^{AB}$={w^{AB}*(resources)=1*, w^{AB}*(pleasant)=4*, w^{AB}*(unpleasant)=2*, w^{AB}*(useful)=5*, w^{AB}*(harmful)=2*, w^{AB}*(obligatory)=0*, w^{AB}*(prohibited)=0*, w^{AB}*(punishment-do)=0*, w^{AB}*(punishment-not)=0*}.

The reasoning procedure NEEDED (Figure 2 above) yields a positive decision in this model. *A*'s *initial information state* is as follows.

Private part

•initial partner model $\boldsymbol{w}^{AB}$ = (1, 4, 2, 5, 2, 0, 0, 0, 0)

•the tactics chosen by *A*–persuasion

•*A* will use the reasoning procedure NEEDED, the presumption is fulfilled: w^{AB}*(useful)* > w^{AB}*(harmful)*

•the set of dialogue acts at *A*'s disposal: {proposal; arguments for increasing/decreasing values of different coordinates of $\boldsymbol{w}^{AB}$; accept; reject}

•the set of utterances for expressing the dialogue acts at *A*'s disposal: {*The company offers you a trip to N, You can be useful for the company*, etc.}.

Shared part

•the reasoning procedures WISH, NEEDED, MUST

•the tactics of enticement, persuasion, threatening

•dialogue history–an empty set.

Let us suppose here that every statement (argument) presented in dialogue will increase or respectively, decrease the corresponding value in the model of beliefs by *one unit*. Still, this is a simplification because different arguments might have different weights for different dialogue participants.

Table 1 demonstrates how the partner model is changing during the dialogue.

Conversational agent *A* starts the dialogue with a proposal. Using the tactics of persuasion and attempting to trigger the reasoning procedure NEEDED in *B*, it adds an argument for increasing the usefulness to the proposal (turn 1). At the same time, it increases the initial value of the usefulness in its partner model $\boldsymbol{w}^{AB}$ by 1. The current reasoning procedure NEEDED still gives a positive decision in the updated model. *A* does not know the actual values of attitudes, which *B* has assigned in the model $\boldsymbol{w}^B$ of herself. As caused by every counter argument that *B* will present, *A* has to update the partner model $\boldsymbol{w}^{AB}$.

However, *B*'s counter argument (turn 2) demonstrates that *B* actually has resources missing (*I don't have proper dresses*) therefore, *A* has to decrease the value of w^{AB}(*resources)* from 1 to 0 in its partner model. Now *A* must find an argument indicating that the resources are available: it selects an utterance from the set $P_{increasing\_resources}$ (*The company will pay your executive expenses*) and following the tactics of persuasion it adds an argument for increasing the usefulness (*You can be useful for the company*) in turn 3. The value of w^{AB}(*resources)* will now be 1 and the value of w^{AB}*(useful)* will be increased by 1 in the partner model. The reasoning in the updated model gives a positive decision.

Nevertheless, *B* has a new counter argument indicating the harmfulness of the action: *I can have some problems at my university* (turn 4).

Now *A* has to increase the value w^{AB}*(harmful)* in the partner model, it turns out that by 6 not by 1 as was assumed by default. Let us explain why. So far, *A* was supposing that *D* is not prohibited for *B*. This assumption proves to be wrong because otherwise it would be impossible for *B* to indicate the harmfulness of *D* (if she is applying the reasoning procedure NEEDED as *A* supposes, see Figure 2). Therefore, *B* supposedly compares the values of beliefs at the step 4 of the procedure and makes a negative decision. *B* can come to the step 4 only after the step 3 where she detects that *D* is prohibited and doing *D* involves a punishment (turn 4).

Table 1. Updating the partner model w^{AB} by *A* in argumentation dialogue with *B* (*A* implements the reasoning procedure NEEDED)

Dialogue history	**Partner model w^{AB}**									**Comments**
	Re-sour-ces	Pleasant	Un-plea-sant	Use-ful	Harmful	Obliga-tory	Prohibited	Punishment_do	Punishment-not	
	1	**4**	**2**	**5**	**2**	**0**	**0**	**0**	**0**	Initial model
`1.A: The company offers you a trip to N.` `Our company needs to conclude an agreement there. statement for usefulness`	1	4	2	5+1	2	0	0	0	0	*A* makes a proposal; usefulness increases
`2.B: I don't have proper dresses. statement of missing resources`	0	4	2	6	2	0	0	0	0	Resources missing
`3.A: The company will pay your executive expenses. statement of existence of resources` `You can be useful for the company. statement for usefulness`	1	4	2	6+1	2	0	0	0	0	Resources exist, usefulness increases once more
`4.B: I can have some problems at my university. statement for harm-fulness`	1	4	2	7	2+6	0	1	1	0	Harmfulness has to be increased by 6 because *B*'s reasoning has given a negative decision
`5.A: It's all right - your examinations period will be extended. statement against harmfulness` `The company will evaluate your contribution. state-ment for usefulness`	1	4	2	7+1	8-1	0	1	1	0	Harmfulness decreases, usefulness increases once more
`6.B: OK, I'll do it. agreement`	**1**	**4**	**2**	**8**	**7**	**0**	**1**	**1**	**0**	Final model
`7.A: I am glad. accept`										*A* has achieved the goal

Therefore, *A* changes the value of w^{AB}*(prohibited)* from 0 to 1 and increases the value of w^{AB}*(punishment-do)* in the partner model at least by 1. (Being optimistic, *A* increases the value exactly by 1 and not more.) Now *A* checks, how to change the value of the harmfulness in the partner model in order to get the negative decision like *B* did. According to the reasoning procedure NEEDED *A* calculates that the value has to be increased (at least) by 6. Therefore, w^{AB}*(harmful)* will be 2+6=8. Responding to *B*'s counter argument, *A* decreases the value of w^{AB}*(harmful)* by 1 using the utterance *It's all right - your examinations period will be extended*, and increases the value of w^{AB}*(useful)* once more using the utterance *The company will evaluate your contribution* (turn 5). The reasoning procedure NEEDED gives a positive decision in the updated partner model. Now it turns out that *B* has made this same decision (turn 6). *A* has achieved its communicative goal and finishes the dialogue (turn 7). Table 1 demonstrates how *A* is updating the partner model $\boldsymbol{w}^{AB}$ in argumentation dialogue with *B*. As compared with the initial model, the values of four aspects have been increased: *w(usefulness)* from 5 to 8, *w(harmfulness)* from 2 to 7, *w(prohibited)* and *w(punishment-do)* from 0 to 1.

Table 2. Updating the model w^B by *B* in argumentation dialogue with *A* (*B* implements the reasoning procedure WISH).

Dialogue history	**The model w^B**									**Comments**
	Re-sources	Pleasant	Un-pleasant	Use-ful	Harmful	Obliga-tory	Prohibited	Punishment_do	Pu-nishment-not	
	0	**6**	**4**	**3**	**4**	**0**	**1**	**0**	**3**	Initial model; reasoning procedure WISH gives a negative decision
1.A: The company offers you a trip to N in order to conclude a contract. proposal Our company needs to conclude an agreement there.	0	6	4	3+ 1	4	0	1	0	3	*A* makes a proposal; usefulness increases
2.B: I don't have proper dresses. statement of missing resources	0	6	4	4	4	0	1	0	3	Resources mis-sing
3.A: The company will pay your executive expenses. You can be useful for the company.	1	6	4	4+ 1	4	0	1	0	3	Resources exist, usefulness increases once more
4.B: I can have some problems at my university. statement for harmfulness	1	6	4	5	4	0	1	0	3	Harmfulness too big, *B*'s reasoning has given a negative decision
5.A: It's all right - your examinations period will be extended. statement against harmfulness The company evaluates your contribution.	1	6	4	5+ 1	4- 1	0	1	0	3	Harmfulness decreases, usefulness increases once more
6.B: OK, I'll do it. agreement	**1**	**6**	**4**	**6**	**3**	**0**	**1**	**0**	**3**	Final model; WISH gives a positive decision
7.A: I am glad. accept										The common goal is achieved

2) Upgrading the model $\boldsymbol{w}^B$

In argumentation dialogue, *A* is updating his partner model $\boldsymbol{w}^{AB}$. At the same time, *B* has to update the model $\boldsymbol{w}^B$ of herself as caused by the arguments presented by *A*. Similarly with *A*, who does not know the exact values of *B*'s beliefs in $\boldsymbol{w}^B$, also *B* does not know the exact values of beliefs in the model $\boldsymbol{w}^{AB}$. Both participants can make inferences only from arguments presented by the partner.

Does the final model $\boldsymbol{w}^{AB}$ coincide with *B*'s actual model $\boldsymbol{w}^B$, i.e., has *A* correctly guessed all the actual weights of *B*'s beliefs? The answer is "no". Let us discuss why.

Let us again consider Example 4 and Table 1. Let us suppose that *B* also is a conversational agent (not a human user) and that *B*'s actual model is $\boldsymbol{w}^B = (0, 6, 4, 3, 4, 0, 1, 0, 3)$ at the beginning of the dialogue (different from $\boldsymbol{w}^{AB}$ as in Table 1). In addition, let us suppose that *B*'s communicative goal coincides with *A*'s one (is not opposite)—*B* has a wish to do *D* (doing *D* is more pleasant than unpleasant). It triggers a reasoning procedure WISH (Figure 1 above) in its model of beliefs in order to check the resources and other aspects of doing *D* and to make a decision. The decision will be negative because *B* does not have enough resources (*I don't have proper dresses*).

Table 2 demonstrates the updates made by *B* in the model $\boldsymbol{w}^B$ during the dialogue as affected by *A*'s arguments. We suppose here that *A*'s arguments will increase/decrease the corresponding weights by *one unit* (this same assumption was made for *A* in the case of *B*'s counter arguments). *B* uses the reasoning procedure WISH. The initial model $\boldsymbol{w}^B$ gives a negative decision but the updated final model gives a positive decision.

In this way, *A* is able to convince *B* to do *D* if he has enough arguments for doing *D* and his initial picture of *B* does not radically differentiate from *B*'s actual beliefs. Both the beliefs in the partner model $\boldsymbol{w}^{AB}$ and *B*'s actual beliefs in the model $\boldsymbol{w}^{B}$ of herself (if *B* is a conversational agent similarly with *A*) are changing during the dialogue as influenced by the arguments presented by the participants. Although the models $\boldsymbol{w}^{AB}$ and $\boldsymbol{w}^{B}$ do not necessarily coincide at the end of the dialogue, the proportions of the values of the positive (pleasantness, etc.) and negative aspects of doing *D* (unpleasantness, etc.) will be similar. Still, if *B* (or *A*) is a human user then she (or he) is not obliged to use the models and algorithms.

V. Discussion

Our model of conversational agent is motivated by the analysis of human-human negotiations. We consider the dialogues where two participants *A* and *B* negotiate doing an action *D*. In the analyzed telemarketing calls, the communicative goal of a sales clerk of the educational company is to convince a customer to order and pass a training course offered by the company. The customer can either adopt or not this goal.

If the participants are collaborative and one of them presents his/her argument then the partner mostly accepts it. If the participants are antagonistic then at least one of them does not agree with the opinion of the partner and presents his/her counterargument(s). The more the clerk knows about the customer, the more convincing arguments is he able to choose. Asking questions is a way to learn more about the communication partner.

The most important phase of a telemarketing call is a clerk's *argumentation* for taking a training course. Arguments of sales clerks are presented as assertions and customers can accept or reject them. It is remarkable that the customers usually accept assertions of clerks—it shows that the clerks succeed to choose 'right' arguments. Still, *B*'s accept is usually followed by additional information that can be interpreted as a counter argument. The argumentation chain looks like

A: argument_1 – *B*: accept_1 + counter argument_1
…
A: argument_n – *B*: accept_n + counter argument_n.

The situation is different when *B* is steering to a negative decision (one single conversation in the whole analyzed corpus). Then *B* does not accept *A*'s assertion/argument and takes over the initiative starting to present assertions/counter arguments herself. *A* always accepts *B*'s assertions but he provides his arguments as additional information. The argumentation chain looks like

A: argument_1 – *B*: reject_1 + counter argument_1
A: accept_2 + argument_2 – *B*: reject_2 + counter argument_2
…
A: accept_n + argument_n – *B*: reject_n + counter argument_n.

When reasoning about doing an action, a subject is weighing different aspects of the action (its pleasantness, usefulness, etc.), which are included into his/her model of motivational sphere. In the model presented here, we evaluate these aspects by giving them discrete numerical values on the scale from 0 to 10. Still, people do not use numbers but rather words of a natural language, e.g., *excellent*, *very pleasant*, *harm*, etc. Further, when reasoning, people do not operate with exact values of the aspects of an action but they rather make 'fuzzy calculations', for example, they suppose/believe that doing an action is more pleasant than unpleasant and therefore they wish to do it. Another problem is that the aspects of actions considered here do not be fully independent. For example, harmful consequences of an action as a rule are unpleasant. In addition, if the reasoning object is different (not doing an action like in our case) then the beliefs of a reasoning subject can be characterized by a different set of aspects.

When attempting to direct *B*'s reasoning to the desirable decision, *A* presents several arguments stressing the positive and downgrading the negative aspects of *D*. The choice of *A*'s argument is based on one hand, on the partner model, which captures *A*'s knowledge about *B*, and on the other hand, on the (counter) argument presented by *B*. Still, *B* is not obliged to present any counter argument but she can simply refuse (e.g., *I do not do this action*). When choosing the next argument supporting *D*, *A* triggers a reasoning procedure in his partner model depending on the chosen communicative tactics, in order to be sure that the reasoning will give a positive decision after presenting this argument. *B* herself can use the same or a different reasoning procedure triggering it in her own model. After the updates made both by *A* and *B* in the two models during a dialogue, the models will approach each to another but, in general, do not equalize. Nevertheless, the results of reasoning in both models can be similar, as demonstrated in Example 4. Therefore, *A* can convince *B* to do *D* even if not having a perfect picture of her.

Our dialogue model considers only limited kinds of dialogue but nonetheless it illustrates the situation where the dialogue participants are able to change their beliefs related to the negotiation object and bring them closer one to another by using arguments. The initiator *A* does not need to know whether the counter arguments presented by the partner *B* have been caused by *B*'s opposite initial goal or are there simply obstacles before their common goal, which can be eliminated by *A*'s arguments. *A*'s goal, on the contrary is not hidden from *B*. Secondly, the different communicative tactics used by *A* are aimed to trigger different reasoning procedures in *B*'s mind. *A* can fail to trigger the pursued reasoning procedure in *B* but however he can achieve his communicative goal when having a sufficient number of arguments supporting his initial goal.

In our implemented DS, the user interacts with the computer, choosing ready-made, semantically pre-classified sentences as arguments and counter arguments for and against doing a certain action. Nevertheless, we suppose that such kind of software is useful when training the skills of finding arguments for and against of doing an action. The computer can establish certain restrictions on the argument types and on the order in their use. Still, when interacting with the computer, a human user does not use neither a formal partner model, nor a formal model of herself, nor reasoning procedures. However, both implementation modes allow study how the beliefs of the participants are changing in negotiation.

VI. CONCLUSION AND FUTURE WORK

We analyse human negotiations in order to explain how arguments are used to convince a dialogue partner. We consider human-human telemarketing calls where a sales clerk of an educational company proposes training courses to a customer who possibly does not want to order any course. When starting a dialogue, the sales clerk determines a certain way to realize his communicative strategy—communicative tactics—and retains them during a dialogue. The customer can change her strategy during conversation.

We study dialogues where one participant (initiator of interaction *A*) has a communicative goal that the partner (*B*) will decide to do an action *D*. *B*'s communicative goal can be similar or opposite ("do not do *D*"). When reasoning about doing *D*, *B* considers different positive and negative aspects of *D*. If the positive aspects weigh more the decision will be "do *D*". If the negative aspects weigh more the decision will be "do not do *D*". The initiator *A* chooses a suitable communicative strategy and tactics in order to influence *B*'s reasoning and achieve the positive decision: he stresses the positive and downgrades the negative aspects of doing *D*. Different arguments are presented in a systematic way, e.g., *A* stresses time and again the usefulness of *D*.

Initial communicative goals of the participants can be similar or opposite. The partners present arguments for and against of doing *D*. The arguments of the initiator *A* are based on his partner model $\boldsymbol{w}^{AB}$ whilst *B*'s arguments—on her model of herself $\boldsymbol{w}^{B}$. Both models include beliefs about the resources, positive and negative aspects of doing *D* that have numerical values in our implementation. Both models are updated during a dialogue.

In our implementation, the user interacts with the computer, choosing ready-made, semantically pre-classified sentences as arguments and counter arguments for and against of performing a certain action. We believe that this kind of software is useful when training the argumentation skills—the programme can establish certain restrictions on the argument types, the order in the use of arguments and counter arguments, etc. It allows study how beliefs of the participants are changing in argumentation dialogue.

Our further aim is to develop the DS concentrating foremost on the reasoning model. So far, we are using an intuitive (naïve) reasoning theory. However, there are several other approaches to model change of a person's opinion, e.g., Elaboration Likelihood Model, Social Judgment Theory, and Social Impact Theory. Some of the theories can be better to model human reasoning. Our further research will explain this. We also plan to add NLP for Estonian in order to achieve more natural communication between DS and the user. The results of the study can be used in various domains of activity, when training people to carry out negotiations.

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Guidelines for Designing Interactions Between Autonomous Artificial Systems and Human Beings to Achieve Sustainable Development Goals

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***Abstract*—Human beings live in an environment that consists of various artifacts, such as physical or virtual tools, information systems, and social systems. With IT advancement, the wider the network of artifacts, the more autonomous they become. However, the ultimate goal of developing these artifacts is to achieve the Sustainable Development Goals (SDGs) through the exploration of the design space for realizing a sustainable society. The artifacts that human beings interact with apply this mechanism for utilizing the artifacts, by selecting the subsequent actions for a given situation. This mechanism includes Perceptual, Cognitive, and Motor (PCM) processes and the memory process. The cognitive process is characterized by the bounded rationality and by the satisficing principle proposed by Simon, and Two Minds of unconscious and conscious processes proposed by Kahneman. The state-of-the art cognitive architecture, Model Human Processor with Realtime Constraints (MHP/RT), developed by Kitajima and Toyota, defines these processes as autonomous systems and proposes a resonance mechanism between the PCM and memory processes. The purpose of this study is to propose guidelines to conduct strategical explorations in design space. Based on the simulation of human–artifact interaction processes through the MHP/RT cognitive architecture, the guidelines are grouped into three levels: goal, mode, and process levels. Moreover, hints are provided for applying the proposed guidelines to narrow down the design space.**

***Keywords*—Design guidelines, Human–artifact interaction; Autonomous systems; Cognitive architecture; MHP/RT.**

I. Introduction

This paper is based on the previous work originally presented in COGNITIVE 2022 [1]. It extends the concepts described in Section IV by providing a new Section IV-A.

When viewed as an individual, *each human being is composed of autonomous systems* that control perception, cognition, and movement in synchronization with changes in the environment, in addition to a memory autonomous system that works to link perception and movements [2][3]. The environment in which humans interact and live is composed of various artifacts. With the progress of networking technology, a large number of artifacts have become related to each other, overcoming the physical constraints of time and space. In this case, the central management method of the set of artifacts and the environment design to achieve their goals is not effective. It would rather be effective *to design the environment as a set of autonomously operating artifacts equipped with Parallel Distributed Processing (PDP)*, which can be referred to as the Artificial PDP (A-PDP) system, and to design them so that they function as a whole and achieve their goals.

There exist interfaces between the above-mentioned autonomous systems, which have to be properly designed for well-being. The interfaces and internal algorithms defining their behaviors must support activities conducted by human beings; they attempt to achieve their happiness goals by utilizing artifacts. A research question that arises is – *how can such interfaces and internal algorithms be designed for the two autonomous systems?* Our daily life is based on interactions with a wide variety of artifacts. The purpose of interactions, for human-beings, is to achieve well-being through activities in domains such as health (e.g., bio-monitoring), mobility (e.g., driving an electric vehicle), education (e.g., learning on Massive Open Online Course (MOOC)), and entertainment (e.g., playing e-sports). The artifacts support human activities through the interface at each moment of interaction. There are multiple autonomous systems on both sides of the interface with complex relationships. The purpose of this study is to propose a set of guidelines that should be applied when designing the interfaces of autonomous artifacts, for supporting activities carried out by autonomous human beings. Traditionally, designers adopt a top-down or a bottom-up approach. It is advised to combine both approaches while designing; the proposed guidelines are useful for this task. The top-down design would be implemented without deviating from the objective by following the guidelines; the bottom-up design would be facilitated by observing user behavior to ensure that the design is in line with the guidelines.

The remainder of this paper is organized as follows. Section II outlines the human-artifact interaction to define the specific perspective for considering the complex situation of interaction, i.e., both sides are autonomous systems. Section III briefly reviews the Model Human Processor with Realtime Constraints (MHP/RT), developed by Kitajima and Toyota [2][3] and defines a framework for developing the guidelines. A set of guidelines are described. In general, guidelines are intended to provide direction for designing artifacts, not to indicate how to proceed with the design according to the specific guidelines provided. Therefore, designers cannot immediately use them in their design activities. To address this issue, Section IV introduces some hints that will be useful in designing interactions according to the guidelines given in Section III.

II. Human–Artifact Interaction

There are human beings on this side of the interface and artifacts on the other side. From the viewpoint of a user that perceives the information provided on an interface to select the next action for accomplishing his/her goal, a complete understanding of the detailed processing of an artifact to generate information on the interface, e.g., the knowledge of implementing the internal algorithms, is unnecessary; similarly, a detailed understanding of the internal processing of an input to an artifact is unnecessary for them to continue the interaction cycle of execution and evaluation. Although the internal processes are not known to the user, s/he has to comprehend the mechanism at the interface level in order to proceed, i.e., "bridging the gulf between execution and evaluation [4, Figure 3.2]." This also applies to the artifacts. For designers to specify the interfaces of the I/O for the systems by developing internal algorithms to support human activities, there is no need for them to have a complete understanding of human reactions to the output of the artifacts and of human expectations attached to the input to the artifacts.

As Simon pointed out [5], an interface is characterized by an artificial system between two environments – inner and outer, i.e., human beings and artifacts, respectively. These environments lie in the province of "natural science" where the systems of artifacts and human beings are the focus of research, but the interface linking them is the realm of "artificial science." Therefore, the research question that this study addresses is in the realm of artificial science. The two sides, i.e., the behaviors of human beings and artifacts, are governed by their own principles, and they have to interact with each other by simultaneously considering the behaviors of the either side at *the appropriate approximation levels* in hope of a successful development. Their articulation could be formalized as guidelines, which is the form of an answer to the research question that this study addresses.

The interface between the two systems can be conceived from a variety of perspectives or dimensions. One of them is the dimension that focuses on the Perceptual, Cognitive, and Motor (PCM) processes and the manner in which memory is acquired, used, and developed in the use of artifacts. This study specifically focuses on the ongoing PCM processes and the manner in which they use the memory in the human–artifact interaction process. Our previous study [6] focused on the acquisition and development process, and proposed guidelines for designing artifacts, which could cause the evolution of artifacts. In the process of evolution, the *techniques* used in the development of artifacts are received and absorbed by users as *skills* by applying the PCM and memory processes, which is simulated by MHP/RT. The techniques could turn into skills if the conditions derived by the simulations based on MHP/RT are satisfied. When this spiral evolution occurs, the socio-cultural ecology, wherein the artifacts are embedded, evolves to exhibit a splicing evolution. The focus of this paper is not on the evolution that occurs at the interfaces but on the ongoing events.

Another dimension, which this study effectively focuses on, is the structure of human goals, which can be used by human beings to organize their behaviors. Our previous paper [7] proposed an effective method for achieving Sustainable Development Goals (SDGs) through the behavior of individual human beings, by applying the knowledge of cognitive science; the idea is to connect the daily activities of human beings when trying to accomplish task goals through real world problem-solving [8], i.e., activities in the COGNITIVE Band of Newell's time scale of human action [9, page 122, Fig. 3-3], through any of the SDGs, that concerns social ecology and resides in the SOCIAL Band by finding the non-linear mappings between the goals in different bands. The interfacing situation this study deals with is analogous to the one above. Each individual human being conducts activities to accomplish his or her behavioral goal. This activity is non-linearly mapped onto the autonomous artifacts, which have the goal of any of the SDGs, where the gulfs of execution and evaluation have to be bridged.

III. Interaction Levels and Guidelines

Figure 1 shows the top-level view of the human–artifact interaction. The artifacts placed at the center should exist as entities for achieving any of the SDGs by providing appropriate support for the individual human beings who try to achieve any of the seventeen happiness goals. This section begins by introducing MHP/RT [2][3] in Section III-A focusing on the levels of interactions with artifacts. It follows Section III-B and Section III-C with suggestions for enabling conditions that artifacts have to satisfy to help human beings achieve a smooth coordination between System 1 and System 2. Section III-D presents the relationships between the happiness goals of human beings and the SDGs that the artifacts are expected to achieve. The top-level constraint for developing guidelines is that any artifact that complies with the guidelines has to provide a stable human-artifact interaction; unstable interactions should result in unpredictable results, which do not come with the SDGs.

A. MHP/RT and Interaction Levels

Kitajima and Toyota [2][3] constructed a comprehensive theory of action selection and memory, MHP/RT, that provides a basis for constructing any model to understand the daily behavior of human beings. MHP/RT is an extension of the Model Human Processor (MHP) proposed by Card, Moran, and Newell [10], which can simulate routine goal-directed behaviors. MHP/RT extends the MHP by the following assumptions to consider the fact that the processes involved in action selection are a dynamic interaction that evolves in the irreversible time dimension:

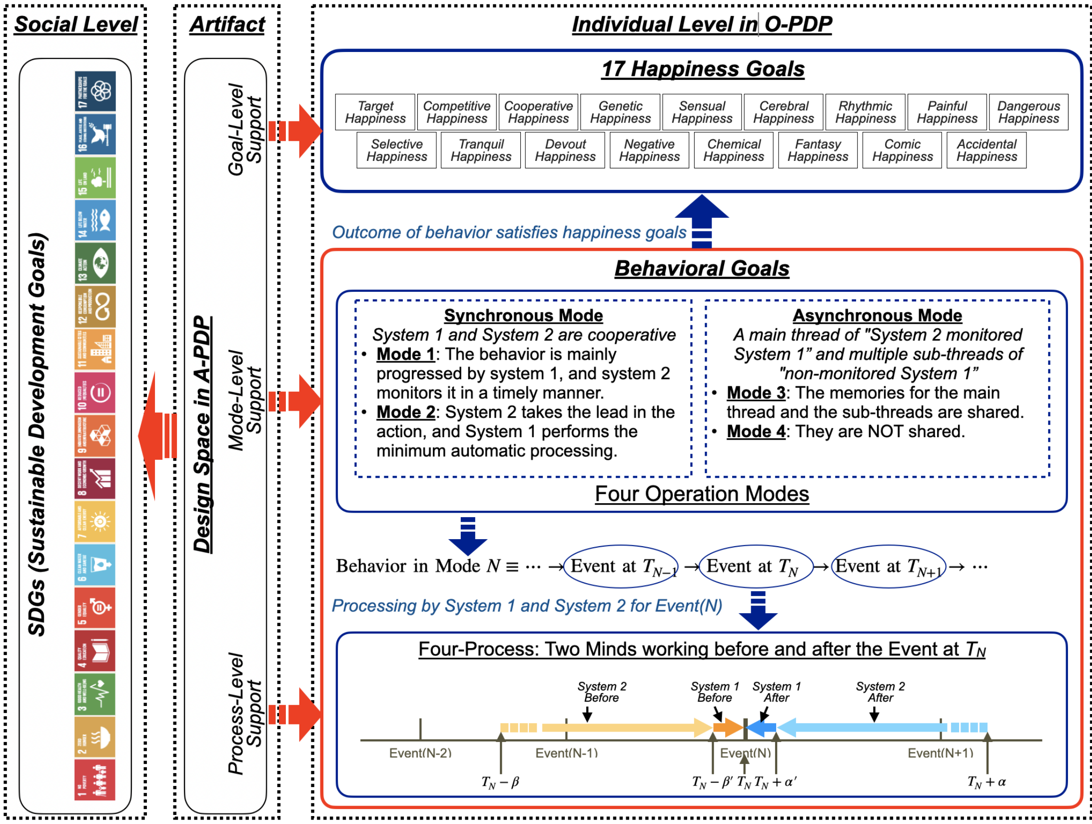


Fig. 1. Top-level view of human–artifact interaction. (adapted from [1])

1) The fundamental processing mechanism of the brain is PDP [11], which leads to a collection of the autonomous systems having specific functions for generating an organized human behavior. It consists of autonomous systems for perception, cognition, motor movements, and memory, which collectively form the Organic PDP (O-PDP) system in the development of MHP/RT.
2) Human behavior emerges as a result of the cooperation of the dual processes of System 1, i.e., fast unconscious processes for intuitive reaction with feedforward control, which connect perception with motor movements, and System 2, i.e., slow conscious processes for deliberate reasoning with feedback control. System 1 and System 2 are referred to as Two Minds [12].
3) Human behavior is organized under 17 happiness goals [13].

Human beings use artifacts to accomplish certain behavioral goals for realizing the desired state of affairs. The human–artifacts interaction is a cycle of PCM processes. The MHP/RT simulates the PCM processes as follows. The cognitive process is to select the next actions that are appropriate for accomplishing the behavioral goals, given the comprehension results of the perceived information. System 1 directly connects to the motor process, whereas System 2 can only indirectly affect the motor process via System 1. The MHP/RT assumes a resonance mechanism for connecting the PCM processes and memory, where the records of the results of the PCM processes are accumulated in a layered and partially overlapped structure of multidimensional memory frames. The cognitive process is carried out by coordinating System 1 and System 2 appropriately to accomplish the behavioral goals. System 1 and System 2 interact simultaneously with the multi-dimensional memory frames to select an appropriate action and carry it out in a timely manner in the ever-changing environment. The former is the issue of coordination, while the latter is that of synchronization. Section III-B and Section III-C will address these issues.

B. Mode Level: Coordination of Two Minds According to the Goals

Individual beings interact with artifacts to accomplish their behavioral goals by selecting appropriate actions, by running a cycle of PCM processes. The MHP/RT assumes that the action selection processes are controlled by System 1 and System 2. System 1 and System 2 cooperate to connect perception with motion, and the degree of cooperation varies depending on the external environmental conditions, i.e., the state of the artifact that the MHP/RT is interacting with.

1) Four Operation Modes: The conduction of the cooperation can be understood by observing the interaction processes for a certain amount of time, to identify the feature of the interaction in terms of the mode. The processes carried out

TABLE I
FOUR OPERATION MODES OF MHP/RT. (ADAPTED FROM [1])

Synchronous Modes	
- Mode 1:	Unconscious mechanism driven mode *A single set of perceptual stimuli initiates feedforward processes at the BIOLOGICAL and COGNITIVE bands to act with occasional feedback from an upper band, i.e., COGNITIVE, RATIONAL, or SOCIAL.*
- Mode 2:	Conscious mechanism driven mode *A single set of perceptual stimuli initiates a feedback process at the COGNITIVE band, and upon completion of the conscious action selection, the unconscious automatic feedforward process is activated at the BIOLOGICAL and COGNITIVE bands for action.*
Asynchronous Modes	
- Mode 3:	In-phase autonomous activity mode *A set of perceptual stimuli initiates feedforward processes at the BIOLOGICAL and COGNITIVE bands with one and another intertwined occasional feedback process from an upper band, i.e., COGNITIVE, RATIONAL, or SOCIAL.*
- Mode 4:	Heterophasic autonomous activity mode *Multiple threads of perceptual stimuli initiate respective feedforward processes at the BIOLOGICAL and COGNITIVE bands, some with no feedback and others with feedback from the upper bands, i.e., COGNITIVE, RATIONAL, or SOCIAL.*

by System 1 and System 2 are independent for some time durations but are totally dependent on each other in other domains. This provides a macroscopic view of the manner in which the human–artifact interaction is organized.

Four qualitatively different modes are identified [14]. System 1 is a fast feedforward control process with the characteristic time range of <150 ms to connect the perceptual process with the motor process, which makes it possible to behave synchronously with the ever-changing environment. There could be multiple System 1 processes that correspond to active perceptual–motor controls. However, System 2 is a slow feedback control process, which takes a significantly longer time. The time range can be months or years as long as feedback from the past event could affect the ongoing processing. System 2 is a serial process. It can process only one thing at a time; the process could be monitoring one of the active threads of System 1 to check for possible deviations of the results of System 1 from the expected course of actions.

Table I lists four modes, each of which is characterized by the relationships between System 1 and System 2. Modes 1 and 2 are characterized by a single major System 1 process monitored by System 2. The differences between them is the degree of intervention of System 2 for checking the output of System 1. In Mode 1, the occasional feedback from System 2 is sufficient to conduct the behavior. In Mode 2, a frequent monitoring is necessary to organize the behavior appropriately in the environment. Mode 3 corresponds to the situation wherein a single set of perceptual stimuli initiates System 1 processes with one and another intertwined occasional feedback processes by System 2. Mode 4 corresponds to the situation where multiple threads of perceptual stimuli initiate the corresponding System 1 processes, some with no feedback and others with feedback from System 2.

2) Guidelines for Supporting Mode Level Interactions: The human–artifact interaction is carried out in one of the four operation modes of MHP/RT. For the viewpoint of a sound human–artifact interaction, the artifacts should support the interactions that are carried out in Mode 1 and Mode 2. Mode 3 and Mode 4 include unmonitored feedforward System 1 processes, which might cause an instability in the human–artifact interaction. The safety of the human–artifact interaction is realized by allowing the artifact to intervene through System 2, causing the human being to restore to the normal interaction. In other words, the resilience of the human–artifact interaction is realized by maintaining the interaction in Mode 1 and Mode 2. Achieving resilience is a necessary condition for the sustainability of the artifacts to achieve the SDGs.

a) Supporting Mode 2 Interaction: In Mode 2, System 2 frequently intervenes the PCM processes conducted by System 1. More precisely, the pace of interaction with the artifact is controlled by System 2. The role of System 1 is to carry out the necessary PCM processes, to advance the main System 2–artifact interactions. Because System 2 operates on language, the appropriate input from the artifact by means of language is of critical importance. Because the processes of System 1 are carried out in the context defined by those of System 2, the appropriate interactions from the artifact for supporting the processes of System 1 have to be provided considering the context.

Guideline [A]

1. *Converse with System 2.*
2. *Intervene System 1 for facilitating the main conversation with System 2.*

b) Supporting Mode 1 Interaction: In Mode 1, where the intervention of System 2 is weak, language is not an appropriate medium for communication. The interaction from the artifact has to support the unconsciously carried out automatic processes by System 1. However, in Mode 1, the timely examination of the progress is critical for a smooth interaction. The triggers for initiating the examinations carried out by System 2 could be provided internally or externally, i.e., from the artifact. There could be a situation where the examination by System 2 has not been carried out when necessary. In this situation, the intervention from the artifact is necessary for maintaining Mode 1 interaction.

Guideline [B]

1. *For a normal Mode 1 interaction, provide information to both System 1 and System 2, so that System 1-led processes can run smoothly.*
2. *For an intensive Mode 1 interaction, e.g., video games and e-sports, focus on System 1 support.*

c) Supporting Transition Between Mode 1 and Mode 2: When the interaction running in Mode 1 breaks down, it becomes impossible to continue. In this case, the accomplishment of the goal via the interaction being advanced is either given up or a remedial action is taken to return from the failed state to the original normal state and resume to the execution in Mode 1. Mode 2 addresses the recovery process.

Guideline [C]

1. *On the detection of the intensive behavior of System 2 during Mode 1 support, switch from Mode 1 support to Mode 2 support.*

C. Process Level: Synchronization of Two Minds with the Environment

The mode-level support described in Section III-B is defined for the interactions that span the extended time along the time dimension. Therefore, its basis is a macroscopic bird's-eye view of the interactions. However, process-level support is defined for each event that occurs along the time dimension. Its basis is a microscopic view for the interaction at the level of each PCM process. The MHP/RT defines four processing modes by considering the manner in which System 1 and System 2 concern the event occurring at time T.

1) Four Processing Modes: Conscious/Unconscious Processes Before/After an Event: Experiences associated with the activities of an individual are characterized by a series of events, each of which is recognized by a person consciously. As shown in Figure 1, the behavior is defined as a time series of events, "$\cdots \rightarrow$ [Event at T_{N-1}] $\rightarrow$ [Event at T_N] $\rightarrow$ [Event at T_{N+1}] $\cdots$." focus on *a particular event* that occurs at the absolute time T_N. For the event to occur at T_N, the MHP/RT assumes that there should have existed the conscious processes of System 2 and unconscious processes of System 1 before T_N. For the executed event at T_N, the MHP/RT assumes that there should exist unconscious System 1 processes and conscious System 2 processes, concerning the event after T_N. The behavior of the MHP/RT appears as though it works in one of four processing modes [2][15] at a time before and after the event at T_N. They are shown at the bottom of Figure 1.

Two of the four processing modes concern the processes carried out *before* the event:

- *System 2 Before Mode:* In the time range of $T_N - \beta \leq t < T_N - \beta'$, where $\beta' \sim$ 500ms and β ranges a few seconds to hours or even to months, the MHP/RT uses a part of the memory for System 2 to *consciously* prepare for future events.
- *System 1 Before Mode:* In the time range of $T_N - \beta' \leq t < T_N$, the MHP/RT *unconsciously* coordinates motor activities to the interacting environment. This mode uses the part of the memory for System 1.

The other two modes concern the processes carried out *after* the event:

- *System 1 After Mode:* In the time range of $T_N < t \leq T_N + \alpha'$, where $\alpha' \sim$ 500ms, the MHP/RT *unconsciously* tunes the connections between the sensory inputs and motor outputs for a better performance for the same event in the future. This mode updates the connections within the part of the memory for System 1.
- *System 2 After Mode:* In the time range of $T_N + \alpha' < t \leq T_N + \alpha$, the MHP/RT *consciously* recognizes an event in the past and then modifies the memory concerning the event, where α ranges a few seconds to minutes or even to hours. This mode modifies the connections of the part of the memory for System 2.

2) Guidelines for Supporting Process Level Interactions: The human–artifact interaction needs to be synchronized for the cyclic PCM processes to run smoothly in any mode, i.e., Mode 1 through 4 defined in Section III-B, the interaction is in. The synchronization between the artifact and user is discussed in [16] in the case of a multi-modal interaction using the concepts of four processing modes. "Synchronization" and its derived concept of "weak synchronization" are defined as follows [17]:

> $\cdots$ a system and a user is synchronized if every system event at T_{sys} occurs as a user event at T_{user} with some amount of time allowance of Δ, $|T_{\text{user}} - T_{\text{sys}}| < \Delta$, where the actual values of Δ depend on the nature of interactions.
>
> $\cdots$
>
> However, a person's activity related with an event has to be considered from the four processing modes, which ranges relatively long time before and after the actual time the event happens. Therefore, "synchronization" has to be considered alternatively as the phenomena a person's activities during the time range of $[T - \beta,\ T + \alpha]$, which are linked with the specific recognizable system event at time T through a sequence of processes carried out in either of the four processing modes: all the processes have some link with the system event at T. When this is satisfied, the event is considered synchronized with a person's activities, which is called *weak synchronization* [16].

The human–artifact interaction has to provide a smooth flow of the four processing modes. It can break when a person has to adjust his/her activity while s/he is in the *System 1*

TABLE II
HAPPINESS GOALS [13] AND THEIR RELATION TO SOCIAL LAYERS. (ADAPTED FROM [1])

Category	No.	Name of Happiness	Types	Social Layers		
				Individual layer	Community layer	Social-system layer
I	8	Painful Happiness	The Masochist	+++		
	11	Tranquil Happiness	The Mediator	+++		
	14	Chemical Happiness	The Drug-taker	+++		
	15	Fantasy Happiness	The Day-dreamer	+++		
II	7	Rhythmic Happiness	The Dancer	+++	+++	
	16	Comic Happiness	The Laugher	+++	+++	
	4	Genetic Happiness	The Relative	+++	+++	
	5	Sensual Happiness	The Hedonist	+++	+++	
III	10	Selective Happiness	The Hysteric	+++	++	
	13	Negative Happiness	The Sufferer	+++	++	
IV	9	Dangerous Happiness	The Risk-taker	+++	++	+
	6	Cerebral Happiness	The Intellectual	+++	+++	++
V	1	Target Happiness	The Achiever	+++	+++	+++
	17	Accidental Happiness	The Fortunate	+++	+++	+++
VI	12	Devout Happiness	The Believer		+++	++
	2	Competitive Happiness	The Winner		+++	+++
	3	Cooperative Happiness	The Helper		+++	+++

+'s denote the degree of relevance of each goal to each layer, i.e., Individual, Community, and Social system, respectively. +++: most relevant, ++: moderately relevant, and +: weakly relevant.

Before Mode in such a way that his/her movement should be in synchrony with the current environment. This is the situation that the interaction has to avoid. This is because when this happens, the condition for weak synchronization is not satisfied. To remedy this, s/he has to make extra efforts to re-establish a weak synchronization by adjusting his/her movement. This leads to the following guidelines.

Guideline [D]

1. *Provide appropriate language-level support for System 2 while the user is in* System 2 Before Mode*,* $T_N - \beta \leq t < T_N - \beta'$.
2. *Provide appropriate perceptual- and motor-level support for System 1 while the user is in* System 1 Before Mode*,* $T_N - \beta' \leq t < T_N$.

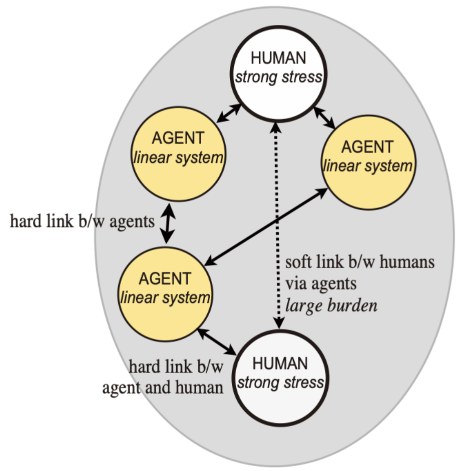
D. Goal Level

The mode-level support described in Section III-B and the process-level support described in Section III-C concern direct interactions with the environment, to accomplish behavioral goals in problem-solving activities, e.g., real-world problem solving [8], or routine goal-oriented skilled activities by applying well-organized knowledge of Goals, Operators, Methods, and Selection rules (GOMS) [10]. As shown in Figure 1, the MHP/RT assumes that the behavioral goals are subordinate to happiness goals; the accomplishment of the behavioral goals are likely to be accompanied by the unconscious feeling of happiness, i.e., achieving a certain happiness goal.

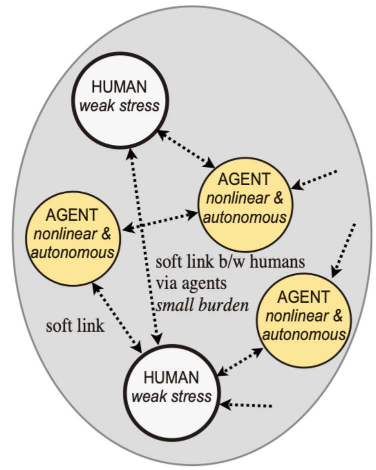
1) Happiness Goals and their Relationship with the Behavioral Goals: Morris [13] listed 17 happiness goals. The left portion of Table II presents them, including goals such as "the inherent happiness that comes with the love of a child," "the competitive happiness of triumphing over your opponents," "the sensual happiness of the hedonist," and so on. Each happiness goal is associated with a type, e.g., the people "the achiever" should have "target happiness," "the winner" should have "competitive happiness," and "the drug-user" should have "chemical happiness."

Kitajima et al. [18] proposed the maximum satisfaction architecture (MSA). MSA assumes that the human brain pursues one of the 17 happiness goals defined by Morris [13] at every moment and switches to another happiness goal when appropriate by evaluating the current circumstances. Each of the happiness goals is associated with one or multiple layers of society. The right portion of Table II presents tentative assignments of the degree of relevance of each happiness goal to each social layer. The middle portion of Figure 1 suggests that any activities for achieving specific behavioral goals would be conducted by individual persons in the pursuit of any of the 17 happiness goals in the social layers presented in the right portion of Table II. Happiness goals define the value structure of the person when he or she makes decisions by running the PCM and memory processes under specific circumstances, while selecting his or her next actions. As such,

	Society of Linear Systems	*Society of Autonomous Systems*
Dimensionality	All systems are 4 dimensional systems	Each system has its own cognitive dimensions
Communication Method	Synchronization	Cooperative autonomous synchronization
Coordination Method	Reconstruction of the entire systems	Autonomous coordination by each system
Number of Systems	Small number of systems acceptable	Large number of systems can participate
Soft Link between Humans	Large burden	Small burden



(a)



(b)

Fig. 2. Society of linear systems and society of autonomous systems.

it is vital to assume the correct happiness goal when supporting the next action selection process of a person, to accomplish the behavioral goals.

There could be associations between the processes of accomplishing behavioral goals and the recognized happiness goals, which could be useful to connect a behavioral goal with a happiness goal. The associations, however, could be vary among individuals. A single observed behavior under a behavioral goal, described in terms of the four operation modes and four processing modes, may have multiple associations with the happiness goals. This is because the condition for feeling happiness is strongly related with individual experiences and the manner in which the reward system functions for that experience [19]. Therefore, the mappings between the behavioral and happiness goals have significant individual and situational differences; a single person could feel different types of happiness when accomplishing a single behavioral goal for different contexts.

2) Guidelines for Supporting Goal Level Interactions: The purpose of designing artifacts has to be linked with any of the SDGs. The design space for artifacts could be explored strategically by associating the targeted SDGs with possible happiness states the user may want to achieve, which is indirectly connected with the behavioral goal of the user [7]. The mode and process level support are truly at the level at which the user could directly interact with. However, the goal-level support is at the level of motivation. The types of happiness goals have discernible aspects of behavioral ecology characterized by individual and contextual differences. Therefore, goal- and contextual-dependent support are needed.

The happiness goals listed in Table II are sorted into six categories according to the degree of relatedness with the social layers, i.e., individual, community, and social-system layers. The categories roughly define the context that the associated behavioral goals are trying to accomplish. The happiness goals in category I could be accomplished individually without any connections with the community or social-system. Those in the category II could be accomplished individually or with the members the individual belongs to. The rest of the categories could be characterized in a similar way. The interface for supporting happiness goals could be designed by category.

Guideline [E]

1. *Provide individually appropriate support for the identified happiness goal that the user might hold when trying to accomplish the behavioral goal.*
2. *Provide contextually appropriate support for the social layer in which the interaction might be conducted.*

IV. Application of the Guidelines: Two Hints

In general, guidelines are policies that indicate the direction to take when designing artifacts, and they do not indicate how the design can be carried out according to the specifically presented guidelines.

The guidelines given in Section III primarily *narrow down the design space in A-PDP* while designing artifacts, as displayed in the center of Figure 1. This can be accomplished

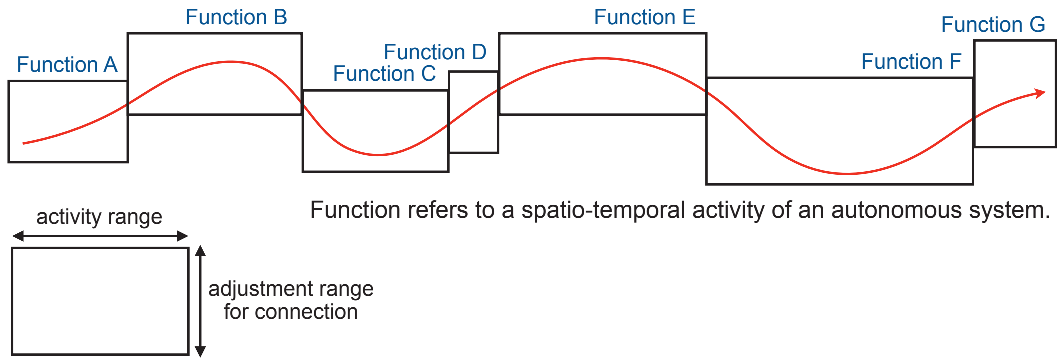


Fig. 3. Successive functions are connected within the adjustable band in the spatio-time dimension (adapted from [17, Figure 6]).

through two approaches. The first approach, presented in Section IV-A, involves deriving a specification of the autonomous decentralized A-PDP system introduced in Section I. This system will enable it to function as a whole and achieve its goals, which are any of the SDGs, and then to apply to it the guidelines derived from human operating principles. The second approach, presented in Section IV-B, involves a reverse engineering approach. First, the interaction process with successful artifacts is observed ethnographically via MHP/RT to understand how the guidelines function in the interaction with the artifact in question. This approach helps ensure that artifacts designed as derivatives of successful artifacts are in line with the guidelines.

A. Autonomous Systems Interaction Design (ASID)

Users behave autonomously, and hence it seems natural to design interactive systems as autonomous systems, which are displayed in Figure 1 as A-PDP. This section reviews a framework for designing interactions between the two autonomous systems, A-PDP for artifacts and O-PDP for individuals, proposed briefly by [20]. Design activities are expected to proceed smoothly by following the design guidelines proposed in Section III.

1) Defining Design Space for ASID: Traditional interactive systems transform their input from the environment to output in the environment by using a set of rules. However, these systems are not intelligent enough to respond to an ever-changing environment including users. Therefore, inputs to a system may drift too far to be treated by the set of rules, and the system might respond inappropriately. In these cases, users may have to deal with the output of the system with some efforts that would not be needed if the system is well designed.

The key idea is to treat interactive systems as autonomous systems that interact with users that are other autonomous systems, and designing interactive systems implies designing autonomous systems interaction that establishes natural cooperation among them. By definition, autonomous systems establish appropriate relationships among themselves at any moment by means of autonomous cooperative synchronization. The environment of an autonomous system is defined by the rest of the autonomous systems. As such, the relationships among autonomous systems are symmetric. In other words, there is no asymmetry in the autonomous systems interaction such as “System A transmits data X (output of System A) to System B (input of System B).” The focus of interactive system design shifts from designing the I/O relationship between the systems and its environment to designing autonomous cooperative synchronization among systems, which we call autonomous systems interaction design (ASID).

Living organisms, O-PDP, establish appropriate relationships with their surrounding environment, A-PDP, by means of autonomous cooperative synchronization. This mechanism is flexible and robust enough to achieve timely and automatic coordination with the environment. The mechanism is modeled by MHP/RT, and the design guidelines shown in Section III are derived by considering the conditions for realizing flexible and stable interactions between O-PDP and A-PDP. When determining the specifications of autonomous systems operating on A-PDP, it is possible to narrow the scope by considering the characteristics of the O-PDP that will be interacting with them. For this purpose, the guidelines described in Section III should be applied.

2) Society of Autonomous Systems: The environment human beings interact with also includes interactive systems. This section starts by describing a society of systems that is linear or autonomous, followed by the needs that those systems must satisfy and the proposal of autonomous system interaction that should meet the requirements.

a) Linear Systems: Behaving objects in the environment are defined in four-dimensional space-time coordinates. A human being viewed as a linear system acquires the information of behaving objects, i.e., humans other than oneself and artifacts surrounding oneself, via its sensory organs as two-dimensional data. The four-dimensional data are reduced to two-dimensional data in this process. The axes that make up these two dimensions are the time axis and a one-dimensional axis representing the feature to which attention is directed.

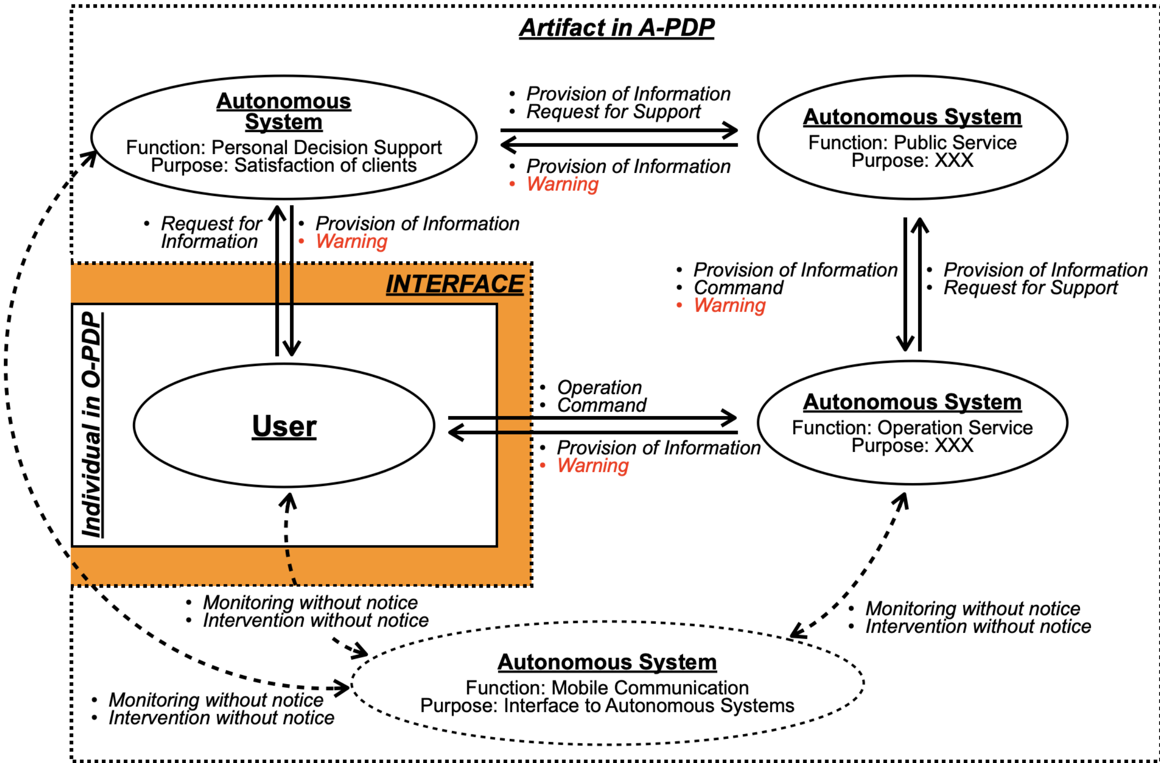


Fig. 4. An illustration of ASID.

The input data are used for representing their characteristics by means of static linear functions. The purpose of the linear functions is to predict the future states of objects. When an objective of a behavior is given, the linear system will behave by deriving static solutions through the use of the linear functions that best match the current situation.

Figure 2(a) illustrates a society of linear systems managing various situations by tuning the relationships among the constituent systems. However, there are situations where the current organization of the systems causes a large amount of stress in spite of efforts made to resolve the situations, and they cannot behave properly. In these situations, the systems have to change themselves. However, the change may or may not produce good results. In the worst cases, the change may cause a rapid increase of stress and crash the system.

b) Autonomous Systems: Human beings viewed as autonomous systems represent behaving objects, i.e., humans other than oneself and artifacts surrounding oneself, in the four-dimensional space-time environment via sensory organs. For example, the sense of taste is represented by six-dimensional data, and the sense of sight is represented by four-dimensional data. The input data are processed mainly by System 1 and optionally by System 2, and they are used to define functions that work in the multi-dimensional memory frames and MSA for accomplishing some of the happiness goals under the real-time constraints for establishing *stable synchronization* with the environment. The functions accumulate personal experience continuously in the multi-dimensional memory frames to be used in the distinctive layers of Newell's Biological, Cognitive, Rational, and Social Bands [9]. When an objective of a behavior is given, the autonomous system will behave by deriving effective regions so that the self will behave properly by using the functions. When an autonomous system communicates with another one, it uses the effective region at each moment. This assures less stressful communication among autonomous systems than among linear systems (Figure 2(b)).

The stable synchronization described above is accomplished by means of weak synchronization [17]. Autonomous elements are weakly synchronized with the external world, and the way they actually work indirectly reflects the circularity of the existing environment, i.e., autopoiesis [21], and fluctuations inherent in the environment. This situation is schematically shown by Figure 3. A function, C, is connected with another function, D, using the region of the overlapping edge for maintaining continuity of the activities. Function C can be a series of conscious activities performed in the Rational Band [9] to plan ahead a sequence of actions for controlling the car by consulting the contents of the relation multi-dimensional memory frame. Function C is followed by Function D, which can be an unconscious activity for tuning the planned activities for the particular road conditions by using the bottom layer of the memory structure, i.e., the perceptual, behavior, and motion multi-dimensional memory frames.

c) An Illustration of Autonomous Systems Interaction (ASI): Using the example presented in Figure 4, the following

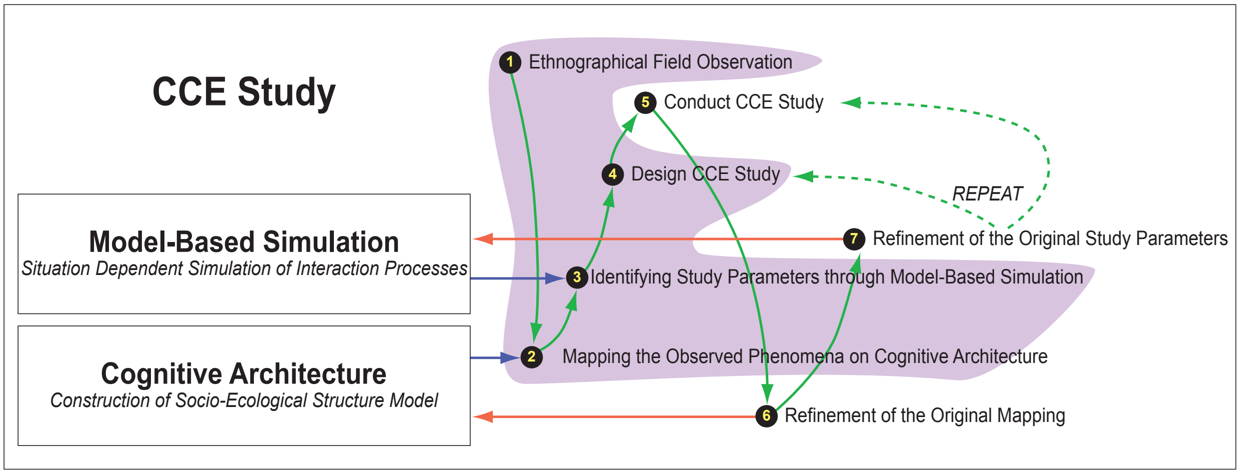


Fig. 5. The CCE procedure [3, Figure 5.1].

illustrates what the interaction of an autonomous system looks like. In real-world interactions between autonomous systems in the A-PDP, the only thing that is predetermined is the communication protocol. Information flows over a bus to an unspecified number of autonomous systems. Figure 4 displays an extract of a portion of this information. A total of five autonomous systems are shown in Figure 4, four in the A-PDP system and one in the O-PDP system, labeled as “User”. The two systems in the A-PDP, the personal decision support system and operation service system, interact directly with the user and provide information or issue warnings when the user requests information or executes operations or commands. Another system in the A-PDP, the public service system, interacts directly with the two systems mentioned above, provides information, and issues warnings in response to requests for support and the given information from them.

The last system in the A-PDP behaves differently from the other systems. This system is the mobile communication system, indicated by the dotted oval in Figure 4. The purpose of this system is to allow the autonomous systems in the A-PDP and O-PDP to synchronize with each other and to facilitate processing. To achieve this, this autonomous system monitors other autonomous systems unnoticed and intervenes with them unnoticed.

As demonstrated in the next section, this autonomous system, which monitors and intervenes unnoticed by other autonomous systems, plays a major role in synchronizing and organizing the interactions among the autonomous systems in A-PDP and O-PDP. However, it is not generally guaranteed that the results of an unnoticed intervention will be meaningful. It depends largely on the circumstances. Therefore, it is necessary to create a feedback system to monitor the impact of the intervention, and if the transition is not in a favorable direction, further interventions to return the system to a normal state are necessary. This would give the autonomous systems in A-PDP and the user in O-PDP the resilience to return to the normal state, thus allowing the entire system to operate in a stable manner.

d) Application of the Guidelines to ASID: The guidelines presented in Section III apply to the design of the portion of the interface displayed in orange in Figure 4. When designing “Provision of Information” and “Warning” displayed in Figure 4, those guidelines that mention “*provide* $\cdots$ *support*”, the Guidelines [D], should be applied. For guideline [D], depending on whether the user is in System 1 Before Mode or System 2 Mode, [D-1] or [D-2] shall apply. It is preferable to determine the user’s state unnoticeably to not affect the natural interaction between the user and the system. For this reason, it is necessary to use the mobile communication system displayed in Figure 4 when applying this guideline.

Guidelines [A], [B], and [C] are to be applied based on the determination of which mode the user is interacting with the system. As this judgment should be made without disturbing the natural interaction between the user and the system, the mobile communication system displayed in Figure 4 should be used. For example, the system intervenes in the interaction between the user and the system without being noticed by the user, naturally prompting the user to request information from the system or providing information from the system to the user that matches the user’s operation mode.

B. CCE

This section introduces a methodology for conducting field experiments to understand human behaviors as a hint for carrying out a strategically principled search in the design space to obtain design specifications that conform to the guidelines this study proposes. The methodology, cognitive chrono-ethnography (CCE) [22], should complement the MHP/RT by providing the real data of human behavior for specific situations that should define constraints on the functioning of PCM and memory processes.

1) CCE for Narrowing Down the Design Space: CCE combines three concepts. “Cognitive” declares that CCE deals with interactions between consciousness and unconsciousness in the PCM cycles. "Chrono (-logy)" is about time ranging from ∼100 ms to days, months, and years, and CCE focuses on these time ranges. "Ethnography" indicates that CCE takes ethnographical observations as the concrete study method because in daily life, the Two Minds of people tend to re-use experientially effective behavioral patterns, which are biases and might have individual and contextual differences.

To conduct a CCE study, study participants (elite monitors) are selected. Each defining study field has values. The study question is "what would certain people do in certain ways in certain circumstances (not average behavior)?" Therefore, elite monitors, certain persons, are selected by consulting the parameter space. In this process, it is necessary that the points in the parameter space, which correspond to the elite monitors, are appropriate for analyzing the structure and dynamics of the study field. The methodology is not for human–artifact interaction but for every aspect of the daily life of human beings. Regarding the relationship between CCE and the design space, CCE focuses on understanding the process of interaction between successful artifacts and users and is intended for existing artifacts. Therefore, it is out of scope to predict the kind of interaction that occurs between the user and a non-existent artifact that no one has discussed. The role of CCE is to enable the design space to be narrowed down by a solid understanding of the success stories of existing artifacts, thereby defining the successful areas of new designs. With that in mind, it will be possible to come up with alternatives to successful artifacts. Whether or not new and innovative artifacts are accepted by users is discussed in another guideline paper published by us [6].

2) CCE Procedure for the Human–Artifact Interaction: Figure 5 shows the seven steps to conduct a CCE study [3, Figure 5.1]. The following describes the CCE steps adapted to human–artifact interaction. Necessary additions appear after the general descriptions for the CCE procedures.

(1) *Ethnographical Field Observation:* Use the basic ethnographical investigation method to clarify the outline of the structure of social ecology that underlies the subject to study.

> The subject of study is to understand the manner in which the existing artifacts in question are used successfully by the current users. The ultimate goal of the artifacts is to achieve any of the SDGs through their use by potential users; the current users may be a part of them. The range of users could be widened by appealing appropriately to the right segments of the users. The users could be characterized as an individual, a member of a community or a social-system. Depending on the social layers the users belong to, the happiness goals that could be achieved could vary. The kinds of SGDs that the artifacts with the current or appropriately enhanced specifications could achieve may be widened or corrected. In this step, it is necessary to clarify the outline of the structure of social ecology in terms of the segment of potential users, the social layer they belong to, and the happiness goals they may achieve by referring to Table II.

(2) *Mapping the Observed Phenomena on Cognitive Architecture:* With reference to the behavioral characteristics of people which have been made clear so far and cognitive architectures, consider what kind of characteristic elements of human behavior are involved in the investigation result in (1).

> This study proposes the use of MHP/RT as the cognitive architecture for this step. As this study proposes, the human–artifact interaction is characterized at three levels, i.e., the mode, the process, and the goal levels. This is based on the MHP/RT cognitive architecture. Because the artifacts in question realize successful interactions with the users, it is assumed that their design should conform to the guidelines in specific ways. In this step, it is necessary to describe the manner in which they conform to the guidelines, i.e., the mode-level support provided, the process-level support, and the goal-level support.

(3) *Identifying Study Parameters through Model-Based Simulation:* Based on the consideration of (1) and (2), construct an initial simple model with the constituent elements of activated memories, i.e., meme, and the characteristic PCM processing to represent the nature of the ecology of the study space.

> In this step, the "what" question answered in (2) is operationalized by turning it into the "how" question. This is answered by constructing an MHP/RT model that could simulate successful users of the artifact in question. The model could run by specifying (a) the likely happiness goals, (b) the possible modes of the assumed interaction, (c) the possible ways of weak synchronization establishment, and (d) the kinds of memes of the simulated user [23][24]. The successful users could be characterized by combining the values assigned to (a) ∼ (d), which constitute the study parameters.

(4) *Design a CCE Study:* Based on the simple ecological model, identify a set of typical behavioral characteristics from a variety of people making up the group to be studied. Then formulate screening criteria of elite monitors who represent a certain combination of the behavioral characteristics, and define ecological survey methods for them.

> This step follows the standard CCE procedure.

(5) *Conduct CCE Study:* Select elite monitors and conduct an ethnographical field observation. Record the monitors' behavior. The elite monitors are expected to behave as they normally do at the study field. Their behavior is recorded in such a way that the collected data is rich enough to consider the results in terms of the parameter space and as un-intrusively as circumstances allow.

> This step follows the standard CCE procedure.

(6) *Refinement of the Original Mapping:* Check the results of (5) against the results of (2) for appropriateness of the mapping. If inappropriate, back to (2) and redo from there.

This step follows the standard CCE procedure.

(7) *Refinement of the Original Study Parameters:* If the result of (5) is unsatisfactory, go back to (4) and re-design and conduct a revised CCE study, otherwise go back to (3) to redo the model-based simulation with a set of refined parameters.

This step follows the standard CCE procedure.

On completion of the CCE cycle, the existing social ecology that characterizes the successful use of the artifact is understood. This understanding is used to widen the range of successful use of the artifact and contribute to determining the direction of strategic development for the maximum utilization of the artifact.

V. Conclusion

The purpose of this study was to contribute to realizing a sustainable society of human beings and artifacts. The focus was on the human–artifact interaction, which occurs at the interface between human beings (the interface is composed of multiple autonomous systems, i.e., PCM and memory systems), and artifacts, which are a collection of autonomous systems. This study used a theory-based approach to derive guidelines for application when designing artifacts that should realize a sustainable society.

The constraints imposed on the derivation were: 1) the ultimate purpose of artifacts for realizing a sustainable society should be the achievement of any of the SDGs, and 2) human interactions with the artifacts should be theorized by the MHP/RT cognitive architecture. These constraints were related with each other via the concept of resilience of the interaction processes. On the one hand, the stability of the human–artifact interaction at the mode level, i.e., either System 2 dominant or System 1 dominant processes should be carried out stably, was the necessary condition for the accomplishment of behavioral goals using the artifact. On the other hand, the accomplishment of behavioral goals is linked with the feeling of achieving any of the 17 happiness goals, defined at the three social layers. The behavioral goals do not necessarily have a direct connection with the SDGs; rather, the accomplishment of behavioral goals indirectly contributes to the achievement of any of SDGs as by-products [7]. Because both the happiness goals and SDGs focus on social ecology, the mapping between them could be established [7]. This would complete the links from the stable accomplishment of behavioral goals to the achievement of happiness goals and SDGs for realizing a sustainable society.

Generally, guidelines are useless, unless they are practiced.

The second hint is related to a method for applying the derived guidelines based on CCE, which defines the experimentation procedure for complementing the theory of cognitive architecture, MHP/RT. CCE and MHP/RT are the two-wheels of a vehicle to understand the daily behavior of human beings [22]; evidently, the human–artifact interaction is part of it. CCE is used to understand observed behavior. Therefore, it is most useful for extending the existing interaction processes by deliberately extrapolating them by the provision of new interface designs, which should conform to the relevant guidelines. For example, at the process level, weak synchronization has to be realized in the interaction process between the new design and the user. If this interaction is carried out as routine goal-oriented skills in Mode 1, the behavior of the users could be represented as several versions of the GOMS models [10] that are suitable for accomplishing respective behavioral goals. The appropriateness of the new design has to be considered, as to whether it could establish weakly synchronized interaction, given the existing GOMS models.

An artifact is defined as a set of specifications, which are sufficient for engineering to realize a working product. The raison d'être of the artifact would be to contribute to the achievement of any of the SDGs and to make its users feel any of the happiness goals, to realize a sustainable society through the human–artifact interaction. This study proposed a method for bridging these goals as a set of guidelines on the basis of the scientific understanding of human behavior, provided by the cognitive architecture, MHP/RT, the methodology for experimentation, CCE, and the design concept for autonomous systems, ASID, to narrow down the design space.

Acknowledgment

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Visibility-based Decentralized Swarm Decision Making Algorithms in 3D Urban Environments

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Abstract— **In this paper, we present a unique and efficient visible trajectory planning for aerial swarm using decentralized algorithms in a 3D urban environment. By using SwarmLab environment, we compare two decentralized algorithms from the state of the art for the navigation of aerial swarms, Olfati-Saber's and Vasarhelyi's. The first step in our concept is to extract basic geometric shapes. We focus on three basic geometric shapes from point clouds in urban scenes that can be appear: planes, cylinders and spheres, extracting these geometric shapes using efficient Random Sample Consensus (RANSAC) algorithms with a high success rate of detection. The second step is a decentralized swarm algorithms for motion planning, demonstrated on drones in urban environment. Our planner includes dynamic and kinematic platform's limitation, generating visible trajectories based on our first step mentioned earlier. We demonstrate our visibility and trajectory planning method in simulations, showing trajectory planning in 3D urban environments for drone's swarm with decentralized algorithms with performance analysis such as order, safety, connectivity and union.**

Keywords-Swarm; Visibility; 3D; Urban environment; Decentlized algorithms.

I. INTRODUCTION AND RELATED WORK

In this paper, we study a fast and efficient visible trajectory planning drone swarms in a 3D urban environment, based on local point clouds data. Recently, urban scene modeling has become more and more precise, using Terrestrial/ground-based LiDAR on unmanned vehicles to generate point clouds data for modeling roads, signs, lamp posts, buildings, trees and cars. Visibility analysis in complex urban scenes is commonly treated as an approximated feature due to computational complexity.

Our trajectory planning method is based on a two-step visibility analysis in 3D urban environments using predicted visibility from point clouds data. The first step in our unique concept is to extract basic geometric shapes. We focus on three basic geometric shapes from point clouds in urban scenes: planes, cylinders and spheres, extracting these geometric shapes using efficient RANSAC algorithms with a high success rate of detection. The second step includes decentralized swarm algorithms for motion planning, demonstrated on drones in urban environment. Our planner includes dynamic and kinematic platform's limitation, generating visible trajectories based on our first step mentioned earlier. We demonstrate our visibility and trajectory planning method in simulations, showing trajectory planning in 3D urban environments for drone's swarm with decentralized algorithms with performance analysis such as order, safety, connectivity and union [1].

Visibility analysis based on this approximated scene prediction is done efficiently, based on our analytic solutions for visibility boundaries. With this capability, we present a local on-line planner generating visible trajectories, exploring the most visible and safe node in the next time step, using our predicted visibility analysis.

For the first time, we propose a solution for decentralized swarm algorithm which takes visibility into account, avoiding obstacles using Velocity Obstacle (VO) search and planning method.

II. VISIBILITY ANALYSIS FROM POINT CLOUDS DATA

As mentioned, visibility analysis in complex urban scenes is commonly treated as an approximated feature due to its computational complexity. Recently, urban scene modeling has become more and more exact, using Terrestrial/ground-based LiDAR generating dense point clouds data for modeling roads, signs, lamp posts, buildings, trees and cars. Automatic algorithms detecting basic shapes and their extraction have been studied extensively and are still a very active research field [2].

In this part, we present a unique concept for predicted and approximated visibility analysis in the next attainable vehicle's state at a one-time step ahead in time, based on local point clouds data which is a partial data set.

We focus on three basic geometric shapes in urban scenes: planes, cylinders and spheres, which are very common and can be used for most urban entities in modeling scenarios. Based on point clouds data generated from the current vehicle's position in state k-1, we extract these geometric shapes using efficient RANSAC algorithms [3] with high success rate detection tested in real point cloud data.

After extraction of these basic geometric shapes from local point clouds data, our unified concept, and our main contribution, focus on the ability to predict and approximate urban scene modeling at the next view point V_k, i.e., at the attainable location of the vehicle in the next time step. Scene prediction is based on the geometric entities and the KF, which is commonly used in dynamic systems for tracking target systems [4],[5]. We formulate the geometric shapes as states vectors in a dynamic system and predict the scene structure the in the next time step, k.

Based on the predicted scene in the next time step, visibility analysis is carried out from the next view point model [6], which is, of course, an approximated one. As the vehicle reaches the next viewpoint V_k, point clouds data are measured and scene modeling and states vectors are updated, which is an essential for the global swarm visible trajectory planning based on state-of-the-art decentralized algorithms.

A. *Shapes Extraction*

1) **Geometric Shapes:**

The urban scene is a very complex one in the matter of modeling applications using LiDAR, and the generated point clouds are very dense. Despite these inherent complications, feature extraction can be made very efficient by using basic geometric shapes. We define three kinds of geometric shapes: planes, cylinders and spheres, with a minimal number of parameters for efficient time computation.

Plane: center point (x,y,z) and unit direction vector from center point.

Cylinder: center point (x,y,z), radius and unit direction vector of the cylinder axis. Cylinder height dimension will be considered later on as part of the simulation.

Sphere: center point (x,y,z), radius and unit direction vector from center point.

2) **RANSAC:**

The RANSAC [7] is a well-known paradigm, extracting shapes from point clouds using a minimal set of a shape's primitives generated by random drawing in a point cloud set. Minimal set is defined as the smallest number of points required to uniquely define a given type of geometric primitive.

For each of the geometric shapes, points are tested to approximate the primitive of the shape (also known as "score of the shape"). At the end of this iterative process, extracted shapes are generated from the current point clouds data.

Based on the RANSAC concept, the geometric shapes detailed above can be extracted from a given point clouds data set. In order to improve the extraction process and reduce the number of points validating shape detection, we compute the approximated surface normal for each point and test the relevant shapes.

Given a point-clouds $P=\{p_1..p_N\}$ with associated normals $\{n_1..n_N\}$, the output of the RANSAC algorithm is a set of primitive shapes $\{\delta_1..\delta_N\}$ and a set of remaining points $R=P\setminus\{p_{\delta_1}..p_{\delta_N}\}$.

B. *Predicted Scene – Kalman Filter*

In this part, we present the global KF approach for our discrete dynamic system at the estimated state, *k*, based on the defined geometric shapes formulation defined in the previous sub-section.

Generally, the Kalman Filter can be described as a filter that consists of three major stages: Predict, Measure, and Update the state vector. The state vector contains different state parameters and provides an optimal solution for the whole dynamic system. We model our system as a linear one with discrete dynamic model, as described in (1):

$$x_k = F_{k,k-1}x_{k-1} \tag{1}$$

where x is the state vector, F is the transition matrix and *k* is the state.

The state parameters for all the geometric shapes are defined with shape center $\vec{s}$, and unit direction vector $\vec{d}$, of the geometric shape, from the current time step and viewpoint to the predicted one.

In each of the current states *k*, geometric shape center $\overrightarrow{s_k}$, is estimated based on the previous update of shape center location $\vec{s}_{k-1}$, and the previous updated unit direction vector $\vec{d}_{k-1}$, multiplied by small arbitrary scalar factor *c*, described in (2):

$$\vec{s}_k = \vec{s}_{k-1} + c\vec{d}_{k-1} \tag{2}$$

Direction vector $\vec{d}_k$ can be efficiently estimated by extracting the rotation matrix T, between the last two states *k, k-1*. In case of an inertial system fixed on the vehicle, a rotation matrix can be simply found from the last two states of the vehicle translations in (3):

$$\vec{d}_k = T\vec{d}_{k-1} \tag{3}$$

The 3D rotation matrix T tracks the continuous extracted plans and surfaces to the next viewpoint V_k, making it possible to predict a scene model where one or more of the geometric shapes are cut from current point clouds data in state *k-1*. The discrete dynamic system can be written as formulated in (4):

$$\begin{bmatrix} \vec{s}_{x_k} \\ \vec{s}_{y_k} \\ \vec{s}_{z_k} \\ \vec{d}_{x_k} \\ \vec{d}_{y_k} \\ \vec{d}_{z_k} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & c & 0 & 0 \\ 0 & 1 & 0 & 0 & c & 0 \\ 0 & 0 & 1 & 0 & 0 & c \\ 0 & 0 & 0 & T_{11} & T_{12} & T_{13} \\ 0 & 0 & 0 & T_{21} & T_{22} & T_{23} \\ 0 & 0 & 0 & T_{31} & T_{32} & T_{33} \end{bmatrix} \begin{bmatrix} \vec{s}_{x_{k-1}} \\ \vec{s}_{y_{k-1}} \\ \vec{s}_{z_{k-1}} \\ \vec{d}_{x_{k-1}} \\ \vec{d}_{y_{k-1}} \\ \vec{d}_{z_{k-1}} \end{bmatrix} \tag{4}$$

where the state vector x is 6×1 vector, and the transition squared matrix is $F_{k,k-1}$. The dynamic system can be extended to additional state variables representing some of the geometric shape parameters such as radius, length etc. We define the dynamic system as the basic one for generic shapes that can be simply modeled with center and direction vector. Sphere radius and cylinder Z boundaries are defined in an additional data structure of the scene entities.

III. Fast and Approximated Visibility Analysis

In this section, we present an analytic analysis of the visibility boundaries of planes, cylinders and spheres for the predicted scene presented in the previous sub-section, which leads to an approximated visibility. For the plane surface, fast and efficient visibility analysis was already presented in [6]. In this part, we extend the previous visibility analysis concept [6] and include cylinders as continuous curves parameterization $C_{c\ln d}(x,y,z)$.

Cylinder parameterization can be described in (5):

$$C_{C\ln d}(x,y,z)=\begin{pmatrix} r\sin(\theta) \\ r\cos(\theta) \\ c \end{pmatrix}_{r=const}, \quad \begin{matrix} 0\le\theta\le2\pi \\ c=c+1 \\ 0\le c\le h_{peds\_\max} \end{matrix} \tag{5}$$

We define the visibility problem in a 3D environment for more complex objects as:

$$C'(x,y)_{z_{const}}\times(C(x,y)_{z_{const}}-V(x_0,y_0,z_0))=0 \tag{6}$$

where 3D model parameterization is $C(x,y)_{z=const}$, and the viewpoint is given as $V(x_0,y_0,z_0)$. Extending the 3D cubic parameterization, we also consider the case of the cylinder. Integrating (5) to (6) yields:

$$\begin{pmatrix} r\cos\theta \\ -r\sin\theta \\ 0 \end{pmatrix}\times\begin{pmatrix} r\sin\theta-V_x \\ r\cos\theta-V_y \\ c-V_z \end{pmatrix}=0 \tag{7}$$

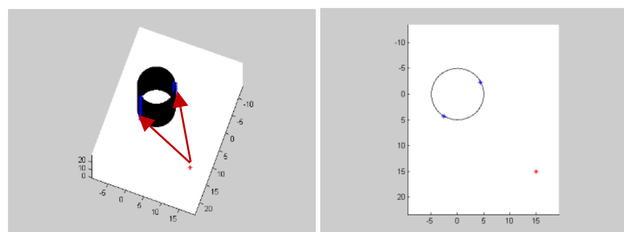
$$\theta=\arctan\left(-\frac{-r-\frac{\left(-vy\,r+\sqrt{vx^4-vx^2r^2+vy^2vx^2}\right)vy}{vx^2+vy^2}}{vx},\; -\frac{-vy\,r+\sqrt{vx^4-vx^2r^2+vy^2vx^2}}{vx^2+vy^2}\right) \tag{8}$$

As can be noted, these equations are not related to Z axis, and the visibility boundary points are the same for each *x-y* cylinder profile, as seen in (7), (8).

The visibility statement leads to complex equation, which does not appear to be a simple computational task. This equation can be efficiently solved by finding where the equation changes its sign and crosses zero value; we used analytic solution to speed up computation time and to avoid numeric approximations. We generate two values of θ generating two silhouette points in a very short time computation. Based on an analytic solution to the cylinder case, a fast and exact analytic solution can be found for the visibility problem from a viewpoint.

We define the solution presented in (8) as x-y-z coordinates values for the cylinder case as Cylinder Boundary Points (CBP). CBP, defined in (9), are the set of visible silhouette points for a 3D cylinder, as presented in Figure 1:

$$CBP_{i=1..N_{PBP\_bound}=2}(x_0,y_0,z_0)=\begin{bmatrix} x_1,y_1,z_1 \\ x_{N_{PBP\_bound}},y_{N_{PBP\_bound}},z_{N_{PBP\_bound}} \end{bmatrix} \tag{9}$$



(a) (b)

Figure 1. Cylinder Boundary Points (CBP) using Analytic Solution marked as blue points, Viewpoint Marked in Red: (a) 3D View (Visible Boundaries Marked with Red Arrows); (b) Topside View.

In the same way, sphere parameterization can be described as formulated in (10):

$$C_{Sphere}(x,y,z)=\begin{pmatrix} r\sin\phi\cos\theta \\ r\sin\phi\sin\theta \\ r\cos\phi \end{pmatrix}_{r=const} \quad 0\le\phi<\pi \quad 0\le\theta<2\pi \tag{10}$$

We define the visibility problem in a 3D environment for this object in (11):

$$C'(x,y,z)\times(C(x,y,z)-V(x_0,y_0,z_0))=0 \tag{11}$$

where the 3D model parameterization is $C(x,y,z)$, and the viewpoint is given as $V(x_0,y_0,z_0)$. Integrating (10) to (11) yields:

$$\theta = \arctan\left(\frac{r\sin(\phi)}{v\_y} - \frac{1}{v\_y\,(v\_y^2 + v\_x^2)}\left(v\_x\left(r\sin(\phi)\,v\_x - \sqrt{-v\_y^2 r^2 \sin(\phi)^2 + v\_y^4 + v\_x^2 v\_y^2}\right)\right), \frac{r\sin(\phi)\,v\_x - \sqrt{-v\_y^2 r^2 \sin(\phi)^2 + v\_y^4 + v\_x^2 v\_y^2}}{v\_y^2 + v\_x^2}\right) \tag{12}$$

Where r is defined from sphere parameter, and $V(x_0, y_0, z_0)$ are changes from visibility point along Z axis, as described in (12). The visibility boundary points for a sphere, together with the analytic solutions for planes and cylinders, allow us to compute fast and efficient visibility in a predicted scene from local point cloud data, which are updated in the next state.

This extended visibility analysis concept, integrated with a well-known predicted filter and extraction method, can be implemented in real time applications with point clouds data.

IV. DECENTRALIZED SWARMS TRAJECTORY PLANNING

In this part, we focus on decentralized swarm algorithms with visibility analysis in urban environment as cost function for our trajectory.

For our simulation, we used SwarmLab [8], drone swarm simulator that was implemented and adapted two representative algorithms belonging to the category of decentralized swarming. Decentralized approach can make the system easily scalable and robust to the failures of a single individual. SwarmLab includes algorithm developed by Olfati-Saber [9], who proposes a formal theoretical framework for the design and analysis of swarm algorithms based on potential fields and graph theory.

The second algorithm that was implemented is an adaptation of the recent Vasarhelyi's algorithm [10], defined by the following rules: repulsion to avoid inter-agent collisions, velocity alignment to steer the agents to an average direction, and self-propulsion to match a preferred speed value. In addition, the algorithm includes friction forces that reduce oscillations and ease the implementation on real robots.

In decentralized approaches, one agent's movement is only influenced by local information coming from its neighbors. Neighbors' selection can be operated according to different metrics.

In this paper, we adopted these algorithms with visibility analysis as part of swarm's trajectory by leading the swarm to the most visible areas in the scene by the swarm, as presented in the previous section.

Unlike the original SwarmLab simulation where obstacle avoidance is based on simulating the obstacles as virtual agents, we used the Velocity Obstacles [11] local obstacles avoidance method.

This obstacle avoidance method allows us to deal better with swarm behavior and can be more precise and gentler, avoiding obstacles in dense environments.

A. *The Planner*

As mentioned above, our planner is based on an iterative local planning method, where the swarm is moving to the most visible area. By using RANSAC algorithm, point clouds data are extracted at each time step into three possible objects: plane, cylinder and sphere. The scene is formulated as a dynamic system using KF analysis for objects' prediction. The objects are approximated for the next time step, and each safe attainable state that can be explored is set as candidate viewpoint. The cost for each agent is set as total visible surfaces, based on the analytic visibility boundary, where the optimal and safe node is explored for the next time step.

At each time step, the planner computes the next Attainable Velocities (AV). The safe nodes not colliding with objects such as cubes, cylinders and spheres, i.e., nodes outside VO, are explored. Where all nodes are inside VO, a unified analytic solution for time horizon is presented, generating an escape option for these radical cases without affecting visibility analysis. The planner computes the cost for these safe nodes based on predicted visibility and chooses the node with the optimal cost for the next time step. We repeat this procedure while generating the most visible trajectory.

B. *Visibility Velocity Obstacles (VVO)*

The visibility velocity obstacle represents the set of all velocities from a viewpoint, occluded with other objects in the environment. It essentially maps static and moving objects into the robot's velocity space considering visibility boundaries.

The VVO of an object with circular visibility boundary points such as the pedestrians' case, PBP, that is moving at a constant velocity v_b, is a cone in the velocity space at point A. In Figure 2, the position space and velocity space of A are overlaid to illustrate the relationship between the two spaces. The VVO is generated by first constructing the Relative Velocity Cone (RVC) from A to the boundaries of the object, i.e., PBP, then translating RVC by v_b.

Each point in VVO represents a velocity vector that originates at A. Any velocity of A that penetrates VVO is an occluded velocity that based on the current situation, would result in an occlusion between A and the pedestrian at some future time. Figure 2 shows two velocities of A: one that penetrates VVO, hence, an occluded velocity, and one that does not. All velocities of A that are outside of VVO are visible from the current robot's position as the obstacle denotes as B, stays on its current course.

The visibility velocity obstacle thus allows determining if a given velocity is occluded and suggesting possible changes to this velocity for better visibility. If PBP is known to move along a curved trajectory or at varying speeds, it would be best represented by the nonlinear visibility velocity obstacle case discussed next.

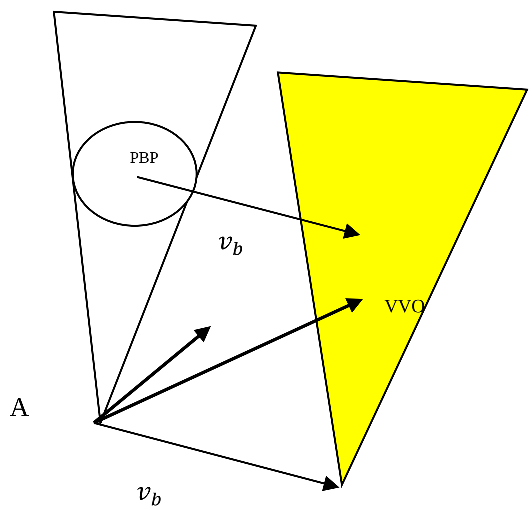


Figure 2. Visibility Velocity Obstacles

The VVO consists of all velocities of A at t_0 predicting visibility's boundaries related to obstacles at the environment at any time $t>t_0$. Selecting a single velocity, v_a, at time $t = t_0$ outside the VVO, guarantees visibility to this specific obstacle at time t. It is constructed as a union of its temporal elements, VVO(t), which is the set of all absolute velocities of A, v_a, that would allow visibility at a specific time t.

Referring to Figure 3, v_a that would result in occlusion with point p in B at time $t > t_0$, expressed in a frame centered at $A(t_0)$, is simply in (13):

$$v_a = \frac{VBP_i}{t-t_0} \tag{13}$$

where r is the vector to point p in the blocker's fixed frame, and visibility boundaries denoted as Visibility Boundary Points (VBP). The set VVO(t) of all absolute velocities of A that would result in occlusion with any point in B at time $t > t_0$ is thus in (14):

$$VVO(t) = \frac{VBP_i(t)}{t-t_0} \tag{14}$$

Clearly, VVO(t) is a scaled B for two-dimensional case with circular object, located at a distance from A that is inversely proportional to time t. The entire VVO is the union of its temporal subsets from t_0, the current time, to some set future time horizon t_h in (15):

$$VVO(t) = \cup_{t=t_0}^{t_h} \frac{VBP_i(t)}{t-t_0} \tag{15}$$

The presented VVO generates a warped cone in a case of 2D circular object. If VBP(t) is bounded over $t = (t_0, \infty)$, then the apex of this cone is at $A(t_0)$.We extend our analysis to 3D general case, where the objects can be cubes, cylinders and circles. The mathematical analysis with visibility boundaries is based on VBP presented in the previous part for different kind of objects such as buildings, cars and pedestrians.

We transform the visibility's boundaries into the velocity space, by moving the VBP to the velocity space, in the same analysis presented for 2D circle boundaries.

Following that, we present a 3D extension for VBP case, transformed to the velocity space.

Given two objects, VBP_1, VBP_2 will create a VVO representing VBP_2 (and vice-versa) such that VBP_1 wishes to choose a guaranteed collision-free velocity for the time interval τ, and visibility boundary in velocity space.

In case of cars, buildings and pedestrians where visibility boundaries can be expressed by geometric operations of 3D boxes, analyzed in the same concept and formulation presented so far, as can be seen in Figure 3.

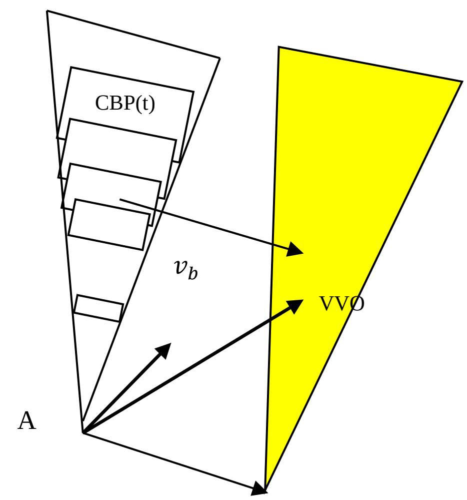


Figure 3. Visibility Velocity Obstacle for visibility boundaries consists of 3D boxes

C. *Pursuer Planner Using VVO*

Our planner, similar to previous work [11] is a local one, generating one step ahead every time step reaching toward the goal, which is a depth first A* search over a tree. We extend previous planners which take into account kinematic and dynamic constraints and present a local planner for UAV as case study with these constraints, which for the first time generates fast and exact visible trajectories based on VVO, tracking after a target by choosing the optimal next action based on velocity estimation. The fast and efficient visibility analysis of our method allows us to generate the most visible trajectory from a start state q_{start} to the goal state q_{goal} in 3D urban environments, which can be extended to real performances in the future. We assume knowledge of the 3D urban environment model, and by using Visibility Velocity Obstacles (VVO) method to avoid occlusion, planner is based on exploring maximum visible node in the next time step and track a specific target.

1) *Attainable Velocities*

Based on the dynamic and kinematic constraints, UAVs velocities at the next time step are limited. At each time step during the trajectory planning, we map the AV, the velocities set at the next time step $t+\tau$, which generate the optimal trajectory, as it is well-known from Dubins theory.

We denote the allowable controls as $u=(u_s,u_z,u_\phi)$ as U, where $V \in U$.

We denote the set of dynamic constraints bounding control's rate of change as $\dot{u}=(\dot{u}_s,\dot{u}_z,\dot{u}_\phi) \in U'$.

Considering the extremal controllers as part of the motion primitives of the trajectory cannot ensure time-optimal trajectory for Dubins airplane model but is still a suitable heuristic based on time-optimal trajectories of Dubin - car and point mass models.

We calculate the next time step's feasible velocities $\tilde{U}(t+\tau)$, between $(t,t+\tau)$ as shown in (16):

$$\tilde{U}(t+\tau) = U \cap \{u|u = u(t) \oplus \tau \cdot U'\} \quad (16)$$

Integrating $\tilde{U}(t+\tau)$ with UAV model yields the next eight possible nodes for the following combinations in (17):

$$\tilde{U}(t+\tau)=\begin{pmatrix}\tilde{U}_s(t+\tau)\\ \tilde{U}_z(t+\tau)\\ \tilde{U}_\phi(t+\tau)\end{pmatrix}=\begin{pmatrix}u_s^{\min}, u_s(t)+a_s\tau\\ -u_s^{\max}\tan\phi^{\max}, u_s(t)\tan u_\phi(t)+u_s^{\max}\tan a_\phi\\ u_z^{\max}, u_z(t)-a_z\tau\end{pmatrix} \quad (17)$$

At each time step, we explore the next eight AV at the next time step as part of our tree search, as explained in the next sub-section.

2) *Tree Search*

Our planner uses a depth first A* search over a tree that expands over time to the goal. Each node $(q,\dot{q})$,where $q=(x,y,z,\theta)$, consists of the current UAVs position and velocity at the current time step. At each state, the planner computes the set of AV, $\tilde{U}(t+\tau)$, from the current UAV velocity, $U(t)$. We ensure the visibility of nodes by computing a set of Visibility Velocity Obstacles (VVO).

The search method is based on exploring nodes which are outside of VVO. The safe node with the lowest cost, which is the next most visible node, is explored in the next time step. This is repeated while generating the most visible trajectory, as discussed in the next sub-section.

Attainable velocities profile is similar to a trunked cake slice, due to the Dubins airplane model with one time step integration ahead. Simple models attainable velocities, such as point mass, create rectangular profile.

3) *Cost Function*

Our swarm direction and movement is guided by minimum invisible parts from viewpoint V to the approximated 3D urban environment model in the next time step, $t+\Delta t$, set by KF after extracting objects from point clouds data using the RANSAC algorithm. The cost function next state is a combination of IRV and ISV, with different weights as functions of the required task.

The cost function presented in (18) is computed for each agent from its current state, considering the agent's future location at the next time step $(x_1(t+\Delta t), x_2(t+\Delta t))$ as viewpoint:

$$w\big(q(t+\tau)\big) = abs(v_a(q(t+\tau) - v_{tck}(q(t+\tau)) \quad (18)$$

where $\propto, \beta$ are coefficients affecting the trajectory's character, as shown in (14). The cost function $w(x(t+\Delta t)$ produces the total sum of invisible parts from the viewpoint to the 3D urban environment.

We divide point invisibility value into Invisible Surfaces Value (ISV) and Invisible Roofs Value (IRV). This classification allows us to plan delicate and accurate trajectories upon demand. We define ISV and IRS as the total sum of the invisible roofs and surfaces (respectively). Invisible Surfaces Value (ISV) of a viewpoint is defined as the total sum of the invisible surfaces of all the objects in a 3D environment, as described in (19):

$$ISV(x_0,y_0,z_0)=\sum_{i=1}^{N_{obj}} IS_{VP_i^{j=1..N_{bound}-1}}^{VP_i^{j=1..N_{bound}-1}} \quad (19)$$

In the same way, we define Invisible Roofs Value (IRV) as the total sum of all the invisible roofs' surfaces, as described in (20):

$$IRV(x_0,y_0,z_0)=\sum_{i=1}^{N_{obj}} IS_{VP_i^{j=N_{bound}}}^{VP_i^{j=N_{bound}}} \quad (20)$$

Extended analysis of the analytic solution for visibility analysis for known 3D urban environments can be found in [12].

V. SIMULATIONS

We implemented the presented algorithm and tested some urban environments on an 1.8GHz Intel Core CPU with

Matlab. We computed the visible trajectories using our planner, simulating cloud points using Matlab functions.

On the first part, we tested our visibility analysis integrated into decentralized drones swarm algorithms as described above. The workflow of a swarm simulation is summarized in Figure 4, were typical scenario of cylinder objects in our environment can be seen in Figure 5.

In the first case, we tested our algorithm with relatively large number of agents. As can be seen in Figure 4, thirty agents in the swarm moving forward in straight line, presenting swarm trajectory, distance between the agents during mission, speed and accelerations during movement. The swarm navigates based on modified Olfati-Saber's algorithm where obstacle avoidance implemented by Velocity Obstacles, where the agents are simulated by point mass model. Swarm cost function is based on visibility analysis computed each time step as mentioned in the previous section.

In the second case, we tested our algorithm with ten agents in the swarm, so each agent simulated with quadrotor dynamic model. As can be seen in Figure 6, ten agents in the swarm moving forward in straight line with Vasarhelyi's algorithm, but visibility analysis and dynamic constraints swift the swarm to the right side. presenting swarm trajectory, distance between the agents. Figure 5 also includes speed and accelerations during movement, performances analysis and total distance to the obstacles during mission.

Order metric captures the correlation of the agents movements and gives an indication about how ordered the flock. S*afety* metrics measure the risk of collisions among the swarm agents or between agents and obstacles.

Union metric counts the number of independent subgroups that originates during the simulation.

Connectivity metric is defined from the algebraic connectivity of the sensing graph that underlines the considered swarm configuration.

Detailed mathematical definitions of these performances' parameters can be found in [8].

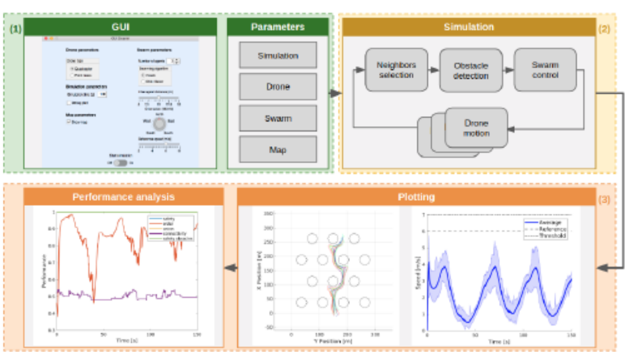


Figure 4. SwarmLab simulation workflow. From the top left, in clockwise order: (1) in the GUI, the user sets the parameters related to the simulation, drone typology, swarm algorithm and environment. (2) the main simulation loop computes control commands for the drones, based on the information of the map and neighboring drones; (3) both real-time and post-simulation (Source [8]).

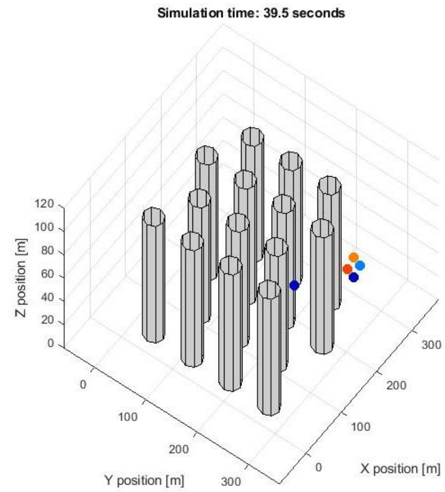
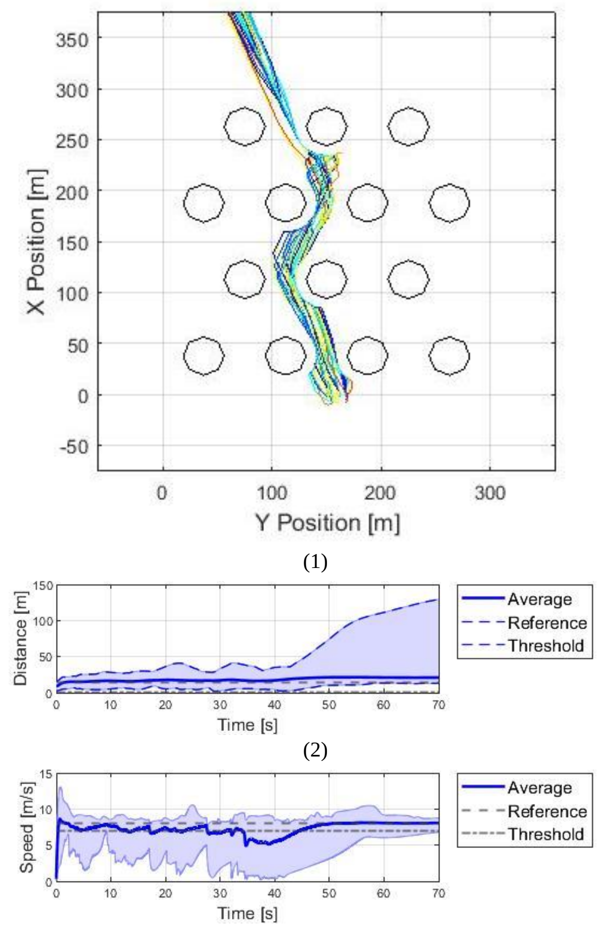
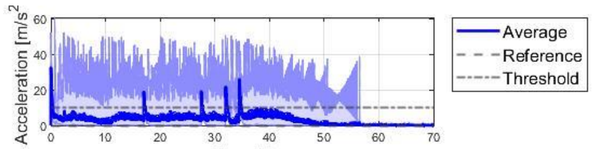


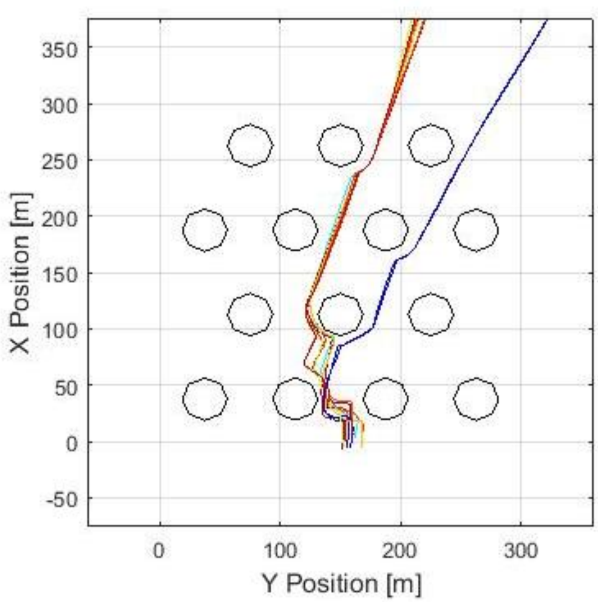
Figure 5. Typical Scenario of Environmmet Obstacles Simulation



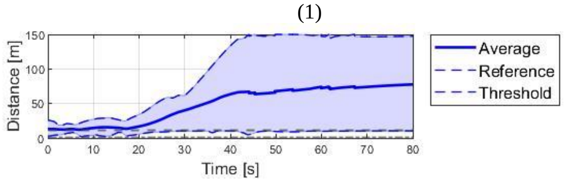


(4)

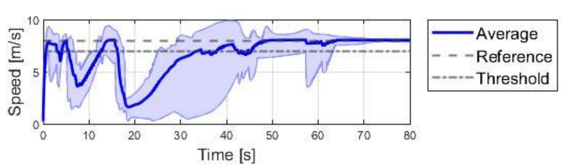
Figure 6. Thirty agents swarm moving forward in straight line using Olfati-Saber’s algorithm with visibility analsysis; (1) presenting swarm trajectory; (2) distance between the agents during mission; (3) speed and (4) accelerations during movement.



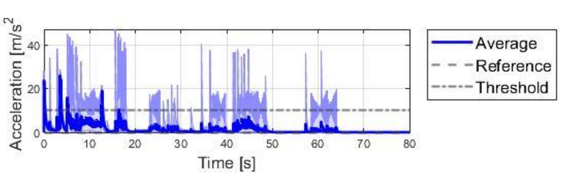
(1)



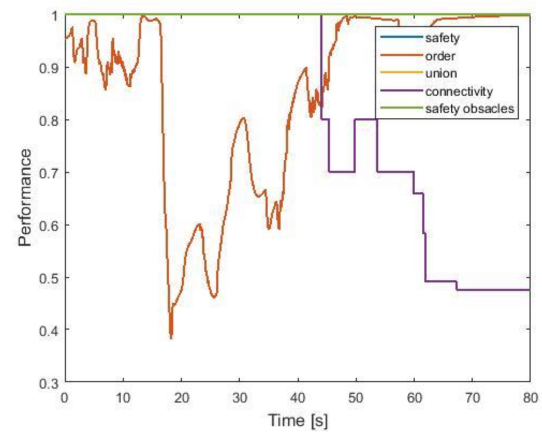
(2)



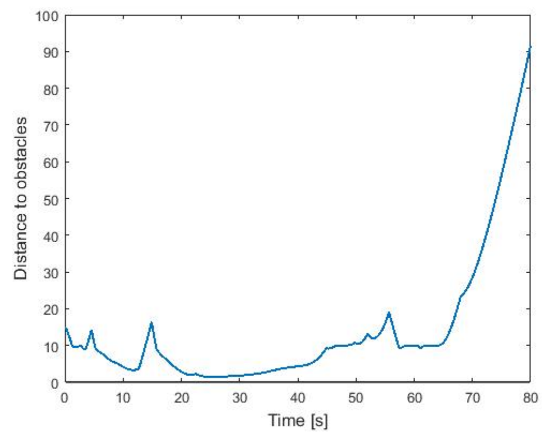
(3)



(4)



(5)



(6)

Figure 7. Ten agents swarm moving forward in straight line using Vasarhelyi’s algorithm with visibility analsysis, with quadrotor synamic model for agent; (1) presenting swarm trajectory; (2) distance between the agents during mission; (3) speed and (4) accelerations during movement; (5) performances analysis; (6) total distance to the obstacles during mission.

VI. CONCLUSION AND FUTURE WORK

In this research, we have presented an efficient swarm trajectory planning algorithm for visible trajectories in a 3D urban environment.

We extend our analytic visibility analysis method to cylinders and spheres, which allows us to efficiently set the visibility boundary of predicted objects in the next time step. Based on these fast computation capabilities, the on-line planner can approximate the most visible state as part of a decentralized swarm algorithms.

By using SwarmLab environment, we compare two decentralized algorithms from the state of the art for the navigation of aerial swarms, Olfati-Saber’s and Vasarhelyi’s.

Our planner includes dynamic and kinematic platform’s limitation, generating visible trajectories based on our first step mentioned earlier.

We demonstrate our visibility and trajectory planning method in simulations, showing trajectory planning in 3D urban environments for drone's swarm with decentralized algorithms with performance analysis such as order, safety, connectivity and union.

Further research will focus on advanced geometric shapes, which will allow precise urban environment modeling, facing real-time implementation with on-line data processing from sensors.

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