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Qualitative and Quantitative Risk Analysis of Unmanned Aerial Vehicle Flights on Construction Job Sites: A Case Study

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***Abstract* - Unmanned Aerial Vehicles (UAVs) have been extensively used on construction job sites in the last ten years. UAVs applications span from progress monitoring and site monitoring to structural health inspection and construction safety. While different applications of UAVs on job sites have been extensively researched, the risks and hazards of flying UAVs on construction job sites have never been quantitatively or qualitatively measured. Around the world, the general aviation industry developed sophisticated methods to evaluate risks of UAV flights over general population. However, in construction domain, discussions over risks of UAV flights is nonexistent. This is particularly interesting as the construction industry constantly maintains one of the highest rates of fatalities and injuries, among all other industries, in the world. Currently, UAVs are used in various construction activities regularly without proper risk assessment schemes or safety plans. Neither construction project managers nor construction safety officers have action plans in place for UAV safe use. This paper presents the first known quantitative and qualitative analyses of UAV flight risks in construction job sites. A quantitative model is presented and tested for UAV flight risk assessment, using the Monte Carlo Simulation technique. A case study tested the proposed model on an actual construction job site. The model proposed in this paper can be used by construction safety officers and construction project managers to take safety into account when planning UAV flights over job sites. This paper further argues that using models and methods introduced in this paper can make UAV flights in any environment safer and more reliable.**

Keywords- Risk Assessment; Unmanned Aerial Vehicle; UAV; Monte Carlo Simulation; UAV flight risk

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have been used in the construction industry for over ten years [1]–[4]. The versatility that UAVs provide enables construction managers, project managers, safety professionals, superintendents and other project team members to capture different types of data, mainly visual data, from locations that might not easily be accessible due to variety of reasons including, but not limited to, high hazards or elevations. UAVs are commercially available, which makes them favorable tools that can be used in even small size construction projects. Relatively low-cost of purchase and operation of new generation UAVs along with the various capabilities that UAVs offer, including high resolution visual imaging, thermal imaging, Radio Frequency IDentification (RFID), laser scanning and other sensing technologies, have played a crucial role in UAVs proliferation in construction research and practice. UAVs are being used on most construction job sites in the United States (U.S.) on daily basis. UAVs have been used for variety of purposes including construction progress monitoring [5], [6], overall site monitoring [6], structural health inspection [8]–[12], surveying job sites and building 3 Dimensional (3D) models [13], infrastructure asset management [14]–[17], urban monitoring [18], material tracking [19], sustainable energy production management [20], and construction safety [21]. In the last ten years, UAV uses and applications in construction have grown exponentially but the risks arise from integrating UAVs into construction job sites, as a new construction equipment, are hardly explored.

In overall, risks associated with UAV flights over general population can be divided into the following two categories:

1- Direct Hazards: Hazards and risks associated with direct impact of UAV-involved accidents; such as falling of a UAV, falling of debris from a collision accident involving a UAV and other elevated objects, other UAVs or other flying objects [22], [23]; and
2- Indirect Hazards: Secondary hazards and risks associated with UAV-involved incidents including hazards associated with the invasion of personal space [24], [24], diverting the attention of workers due to the UAVs' sound and motion (thereby increasing their cognitive load while performing their tasks [26]–[28], and invasion of a workers' personal space [29].

Construction is one of the deadliest industries in the U.S. Unfortunately, the highest rates of fatalities and injuries usually belong to the construction industry. This asks for immediate action from the construction industry to prevent fatality and/or injury on job sites as soon as possible. In the U.S. alone in 2015 and 2016, more than 900 cases of fatalities are reported in the construction domain. In 2015 around 4,836 job related fatalities occurred in the U.S.; out of these 4,836, almost 20% occurred in construction. In construction, falls, slips and trips are the most common cause of fatal incidents, with 364 cases. Transportation incidents were the second highest cause (with 226 cases) and contact with objects came third (with 159 cases) [30]. Many of these incidents are equipment-involved. These statistics show the crucial role that construction equipment plays in safety incidents that happen on construction job sites. It also reminds construction professionals that there is an immediate need for better monitoring job site safety conditions and the extent that safety rules, regulations and procedures on job sites are being followed. It is fatefully important to have the safety of construction equipment in check at all time in order to avoid any accident. It is not difficult to provide a safe environment of use for traditional construction equipment such as excavators, loaders, and cranes as they are thoroughly regulated due to prolong use on construction job sites. However, regulating safe use of more innovative types of construction, equipment such as UAVs, is a critical job; as there are not many, if any, rules and regulation concerning the safe use of newly introduced equipment to construction job sites. In case of UAVs, there is no specific rule regarding safe use in construction environments. Only rules and regulations that are concerned with safe use of UAVs are the Federal Aviation Administration (FAA) general rules that govern the safe UAV flights in public, and over general population. The lack of a comprehensive qualitative and quantitative methodology for risk assessment of UAVs operations on construction sites coupled with a rapid increase in their use pose a new safety threat that requires attention. This paper investigates the risks associated with UAV flights on construction job sites. It further aims at evaluating quantitative and qualitative UAV flights risks on construction job sites by proposing quantitative and qualitative approaches that can measure risks associated with UAV flights over construction job sites under certain circumstances. This paper proposes the first ever known model to quantify UAV flight risks on construction job sites. A case study is presented in later sections, which shows the applicability of the proposed risk model. In this case study, risks of UAV flights over construction job site of an under-construction building at the University of Florida is quantitatively and qualitatively measured to demonstrate the proposed model applicability and significance. An earlier version of this paper [1] presented in Eighth International Conference on Advanced Communications and Computation (INFOCOMP 2018) in Barcelona. This paper presents a more in depth discussion on the topic and is an extended version of the conference papers.

II. RULES AND REGULATIONS GOVERNING UAV FLIGHTS IN THE UNITED STATES

The FAA oversees the U.S. civil aviation for the Department of Transportation. Small Unmanned Aerial Systems (UAS) (a broader category for UAVs) definition concerns UAS weight. The small UAS means an unmanned aircraft with a take-off weight of less than 55 lbs., including everything that is on board or otherwise attached to the aircraft. The FAA published the regulations Part 107 for small UAS operation as the following [31][32]:

(1) Limitations for Flight speed, altitude, and space of small UAS. The ground speed of small UAS may not exceed 100 miles per hour. The flying height of small UAS cannot exceed 400 feet above the ground unless the UAS is flown within a 400-foot radius of a structure and does not exceed 400 feet above the structure's immediate uppermost limit. In addition, the minimum flight visibility of small UAS must be no less than 3 miles from the control station. The minimum vertical distance of the UAS from clouds must be no less than 500 feet below the clouds and the minimum horizontal distance from the clouds must be no less than 2,000 feet (Section 107.51);

(2) Operation of a small UAS is prohibited during the night. In addition, the small UAS cannot be used during periods of civil twilight unless the small unmanned aircraft has lighted anti-collision lighting visible for at least 3 statute miles (Section 107.29);

(3) With a vision that is unaided by any device other than corrective lenses (including contact lenses), the remote pilot in command, the visual observer, and flight control operators must be able to see all flight operations of the small UAS (Section 107.31);

(4) A small UAS cannot be flown above a person unless the person: (a) is directly involved in the operation of the small UAS; or (b) is inside a covered structure or a stationary vehicle which can provide reasonable protection against a falling of the small UAS. (Section 107.39)

(5) A person cannot operate or act as a remote pilot in command or visual observer in the operation of multi-UAS at the same time. (Section 107.35)

(6) No person is allowed to operate a small UAS on a moving aircraft, on a moving land or water-borne vehicle unless the operation requires the small UAS to fly over a sparsely populated area and is not transporting another person's property for compensation or hire. (Section 107.25)

(7) Operation near aircraft and right-of-way rules: Each small UAS must yield the right of way to all aircraft, airborne vehicles, and launch and reentry vehicles. Yielding the right of way means that the small UAS must give way to the aircraft or vehicle and may not pass over, under, or ahead of it unless well clear. [Section 107.37 (a)] In addition, no one may operate a small UAS approaching another aircraft to avoid the risk of collision. [Section 107.37 (b)]

(8) Prohibition of Dangerous Work. No person may (a) operate a small UAS with carelessness or recklessness to endanger the life or property of another; or (b) allow to drop objects from small UASs in a manner that may cause undue harm to persons or property on the ground. Small UASs cannot carry dangerous substances. (Section 107.25)

(9) Operation near airports: Small UASs must not interfere with the normal operation (take-off and landing) of any airport, helicopter airport, or seaplane base. (Section 107.25)

(10) Small UASs may not be flown in prohibited or restricted zones unless the person manipulating the UAS has the permission issued by the controlling agency. (Section 107.45)

This research made the following assumptions based on the most critical aspects of the FAA regulations for small UAS: (1) the construction site mentioned in the case study is not located within a five mile radius of any airport; (2) the operations of the UAV used in the research are following all FAA regulation; (3) the UAV is flown within the vision line-of-sight of the remote pilot in command, the operator, and the visual observer; (4) the specifications of UAV in this research comply with FAA regulation, and more importantly (5) UAV were not flown over any person for safety consideration. These assumptions are specifically highlighted in the qualitative risk analysis that is provided in the discussion and conclusion sections.

III. RISKS OF UAV FLIGHTS

A. *Quantitative Risks of UAV Flights*

Quantifying risks of UAV flights over construction job sites is the main step in decision making process of UAV safety on job sites. By quantifying the risks of UAVs, superintendents, construction project manager, construction safety managers, insurance companies and other decision makers can have a clear view of the risks associated with UAV flights under certain circumstances. A quantifiable risks analysis of UAV flights will give insurance companies a better insight into the value, extent and severity of risks associated with UAV flights on construction job sites. It also helps the decision makers to make rational, informed and scientific decisions on the issue of UAV safety on job sites. In risk management, risk is assumed to be the product of probability of occurrence and impact (Eq. (1)).

$$\text{Risk} = \text{Probability of occurrence} * \text{Impact} \quad (1)$$

In order to develop a model for UAV flight risks on job sites, first step is to define *Probability of occurrence* and *Impact*. This paper uses some of the risk models that have been extensively used in the general aviation industry (1) as the bases for developing a risk model that fits UAV flight risks on construction job sites, and (2) to quantify the probability of occurrence and impact. In general aviation industry Clothier and Walker [23], proposed a model that defines and measures the ground fatality expectations of flights. The model measures and enumerates the risk of expected ground fatalities based on the chances that a UAV flight might fail and/or due to falling debris of a UAV involved incident. It is worth noting that this model only quantifies the direct risks of falling UAVs, and/or debris. This model does not consider the indirect risks associated with UAV flights.

Some of the indirect risks that are not considered in this model but could have a crucial impact on safety are: (1) threatening workers' personal space, (2) threatening privacy of workers, (3) potential distraction of workers due to UAV on-board lights and (4) potential distraction of workers due to UAVs noise and motion.

Clothier and Walker [23] proposed the ground fatality expectation model of UAV flights as below:

$$SO = MR * \varphi * AL \quad (2)$$

In this model SO is the Safety Objective in terms of the number of fatalities per flight hours. The φ refers to the population density of the area under flight path of the UAV. This area is the exact area under UAV flight path in which UAV can maneuver. The AL (sometimes shown as A_L) is called the lethal area. The lethal area refers to the circular area around the UAV which is measured by using a diameter of maximum length of UAV diameter plus a (safety) buffer. Lethal area is believed to be the area of direct impact in case of a falling UAV. As demonstrated in Eq. (2), the bigger this lethal area, the larger would be the ground fatality impacts due to a flight failure or accidents. MR is referred to the mishap rate. Mishap rate is calculated using the formula in Eq. (3).

$$MR = SFR + MC\textit{Debris} + \text{Other} \quad (3)$$

In this formula, SFR is referred to System Failure Rate, which is measured per (million) flight hour(s). The MC*Debris* refers to the quantity of debris from a possible midair collision per flight hour. While MC*Debris* is a factor that is hard to measure, it is possible to assume a probability or an estimate this factor. It is also possible to assume that there will be no injuries and/or fatalities due to debris. In this paper MC*Debris* is assumed to be zero as estimating *MCdebris* in construction context is not possible due to lack of data. The last factor is *Other*. This factor refers to the other types of hazards that might result in fatality risks. Like MC*Debris*, for this factor, it is possible to assume a probability, an estimate or no value at all. Sometimes lack of data could result in avoiding the use of MC*Debris* and *Others*.

B. Qualitative Risks of UAV Flights

As discussed in Section II, FAA established a series of general rules and regulations for UAV flights in the national air space. Out of all FAA rules, two rules and regulations are specifically very significant for the construction industry. These two are as follow: (1) never fly a UAV out of the pilot's line of sight and (2) never fly a UAV over a populated area. The implementation of these two would mean that it is not legal for construction managers to (1) allow a UAV flight over general population close to the construction job sites, (2) allow a UAV flight over construction personnel working on job sites and (3) allow a UAV flight over and close to construction machinery and equipment on job sites. It is vital for construction project managers, superintendents and construction safety managers to guarantee the safety of construction personnel working on site. When it comes to UAV flights, the three qualitative measures outlined above have to be strictly enforced in order to avoid any violation of FAA rules and regulations and make job sites safer. As it is outlined in Section II, the rest of the rules outlined by FAA are assumed to be enforced by the project team. Some of them such as distance from airports are to be checked on a case by case basis by the project team in order to assure the safety of UAV flights on job sites.

Based on these specific regulations, authors developed a qualitative safety map for UAV flights over the job site that has been used as a case study in this research and is presented in the analysis and discussion sections.

IV. MONTE CARLO SIMULATION AS A RISK ASSESSMENT METHOD

Monte Carlo simulation (MCS) is named for the well-known gambling capital of Monaco and is essentially a random number generator technique [33]. As MCS generates a large quantity of sample paths of outcomes for prevalent features analysis, it is widely used for risk analysis, risk quantification, sensitivity analysis, and prediction [34]. With the rapid advancement of computing technology, computers become competent of modeling reality and assisting in decision making by taking account of randomness and uncertainties via exploring various scenarios. Through calculating the values of the modeled scenarios, a more reliable decision can be made through use of MCS [33].

With great ease, MCS has been widely adopted by scholars and practitioners in a broad spectrum of disciplines to solve thorny and sophisticated problems [33]. The most famous application was probably by Enrico Fermi, a Nobel Laurent in physics in 1930, to study the properties of the newly discovered neuron. MCS was also a core technique for the Manhattan Project in 1950s [33][34]. Its application was then expended to engineering, research and development, business, and finance [33]. Thompson et al. [35] employed MCS in a public health risk assessment research to account for uncertainties. Burmaster and Anderson [36] proposed 14 principles of good practice in conducting and evaluating MCS-based risk assessments for hazardous waste sites. Stroeve et al. [37] substantiated the feasibility of using MCS for air traffic safety assessment. Au et al. [38] proposed an upgraded MCS with an ability to accommodate rare failure events commonly seen in engineering for compartment fire safety. To copy with the high transaction costs and financial risks for renewable energy technologies, Arnold and Yildiz [39] introduced MCS for risk analysis through representing the lifecycle of a renewable energy technology investment project. Their research uncovered tremendous advantages concerning content and methodology over the traditional NPV estimation or sensitivity analysis. Arunraj et al. [40] combined fuzzy set theory with MCS for industrial safety risk assessment, which was used to a benzene extraction unit (BEU) of a chemical plant.

MCS also comes into the radar of scholars in the construction community and has gained great popularity. MCS has typically been used in conjunction with other techniques in construction management related research. Rausch et al. [41] applied MCS in off-site construction to mitigate rework risks through tolerance analysis. To deal with data scarcity and uncertainty, Kwon et al. [42] incorporated MCS into Case-based reasoning to estimate cost compensation in construction noise disputes. Kim and Lee [43] employed MCS with a genetic algorithm in the last step of their prediction model development for the engineering maturity effect on oversea megaprojects.

MCS is a favorable tool for UAV related studies. To ensure low altitude safety, Chen et al. [44] used MCS to evaluated the effectiveness and robustness of a proposed UVA and bird targets tracking and recognition model using surveillance radar data. Similarly Lu et al. [45] utilized MCS to validate an approach proposed to improve the performance of direction arrival estimation of UVAs for low signal-to-noise ratios. Dabiri et al. [46] verified the reliability of a channel modeling and parameter optimization system for UAV-based free space communication using multi-rotor UAVs.

As UAVs are increasingly prevalent on construction projects, this phenomenon poses a series of safety related risks to the construction workers and properties on job sites due to obstacles, operational mistakes, and inclement weather. Plioutsias et al. [47] discovered that small UAVs were typically neglected for hazard analysis among researchers and practitioners and identified 20 hazardous types. Izadi Moud et al. [48] presented a quantitative tool for UAV flying risk assessment on construction jobsites in combination with qualitative analysis by considering FAA rules and regulations on safety specifications of UAVs. Izadi Moud et al. [48] applied the previously developed risk quantification model to a real-world case based on malfunction rate of UAVs, population density of the area covered by UAVs flight routes. Izadi Moud et al. [49] further studied the indirect risks of UAVs operations on construction sites, in which MCS was employed in measuring the proximity between UAVs and construction workers.

On construction job sites, small UAVs require safety consideration due to uncertain operational conditions, such as their weak structural shape that may cause instability and failure in windy weather, their potential for operational errors, as well as their high maneuverability and potential for mechanical failures. Plioutsias et al. [47] published a research paper that concludes current commercial UAVs are very far from being able to meet safety requirements. To simulate collision and other hazards between one or multiple UAVs operating on construction sites and their bordering area, use of MCS method offers flexibility and accuracy in simulation. This method is playing an important role in modeling uncertainties, such as the movement of different kinds of object on a construction site and environmental factors, such as wind [50]-[53].

V. ANALYSIS OF THE CASE STUDY

This section presents Analysis of Quantifying Risks of UAV Flights and Analysis of Quantifying Risks of UAV Flights.

A. Analysis of Quantifying Risks of UAV Flights

In this section, MCS is used to assess the risk of flying UAVs over construction job sites, which is referred to as the Safety Objective (SO) as described by Eq. (2). Mishap Rate (MR), the Lethal Area (AL) and the density of population (φ) are needed to find the SO in each area. MR is the variable with the least empirical data as there is not much information recorded on the MR of UAVs. In this analysis, it is assumed that the UAV lifetime, or the duration over which possibilities of crash exist, is normally distributed, with a range between 100 hours and 10,000 hours, a mean of 5,050 hours, and standard deviation of 1,650 hours. MR is referred to as the rate of failed UAV flights in a given lifetime for a UAV. In this case, the normal productive life of a UAV is estimated to be in this range. As a result, MR is calculated as one crash in a UAV's lifetime: 1 / (lifetime of UAV in flight hours).

AL is the area that has the potential for lethal impact from the UAV or debris if a UAV crashes. Typically, it is calculated by using the longest dimension of a UAV. In this case, considering the fact that most of the UAVs flying over construction job sites are commercially available, it is presumed that AL can assume a value between 0.3 m and 1.8 m. Thus, an even distribution across a diameter with a minimum of 0.3 m and maximum of 1.8 m is used in the simulation. The density (φ) represents the number of personnel on the site divided by the area of the location that a UAV flies over. In this study, it is assumed that only construction workers are present at the job site. Due to a lack of empirical data, it is estimated that the number of construction personnel on the job site varies between 2 and 14 with a normal distribution (a mean of 8, a standard deviation of 2). The density is calculated for Area 1 to Area 4 by dividing the sampled number of construction workers for each zone by its area. The area of each location that a UAV can fly over is calculated and shown in Figures 1 and 2. The area surrounding the job site is divided into Area 1 through Area 4 using the logic of FAA regulations regarding safe UAV flights, which prohibits UAV flights over head of people, in this case construction personnel sidewalks and pathways. Thus, considering the pathways that construction personnel routinely commute between workstations and the job site, four separate areas are drawn as separate areas that UAVs can fly over. Due to these regulations, UAVs cannot fly from one of these areas to another because they need to fly over a construction personnel pathway, which is prohibited by FAA regulations.

Figure 3 depicts the resulting distribution for density (φ) for area 1. The representative population density distribution for area one is a normal distribution with mean of 0.001061765 and standard deviation of 0.000262214.

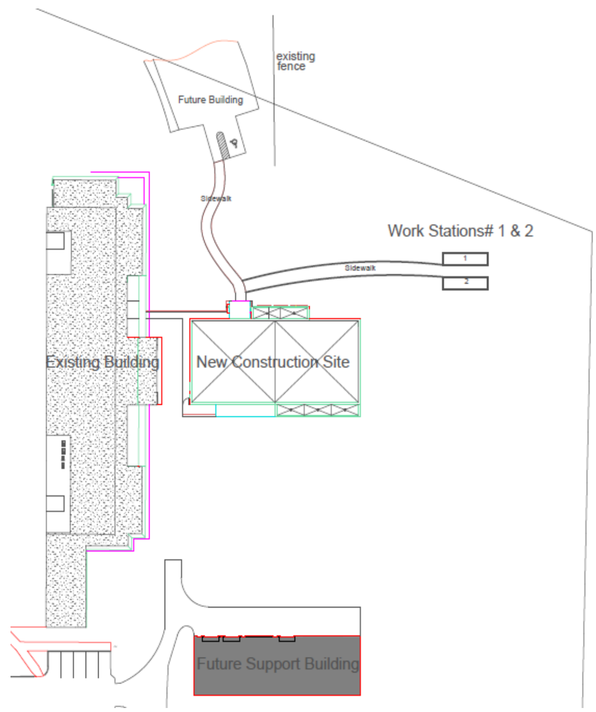

Figure 1. General layout of the construction site.

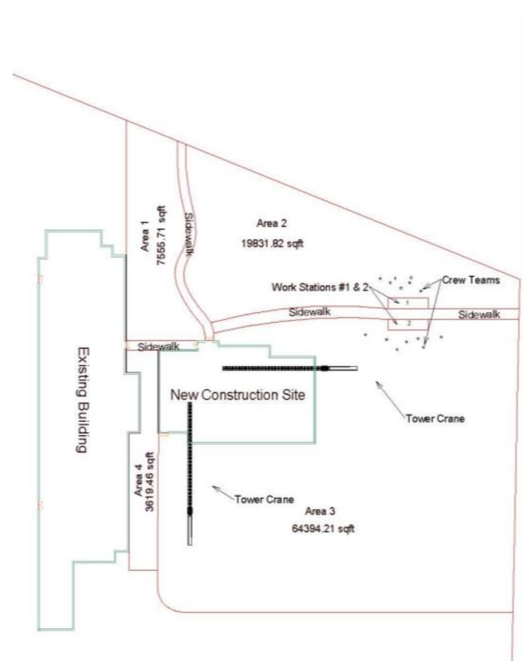

Figure 2. simplified layout for analysis.

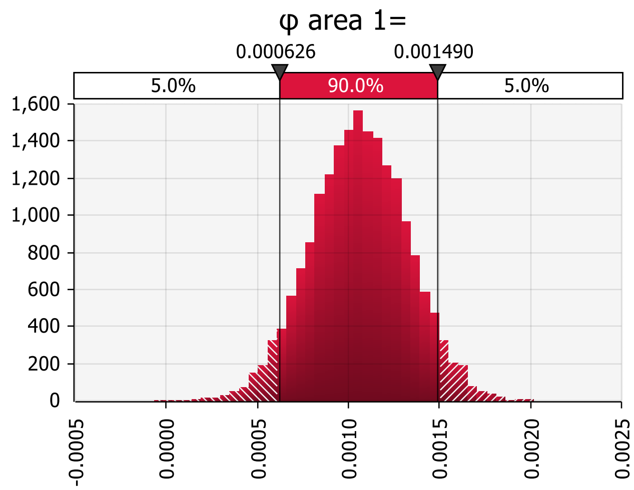

Figure 3. Resulting φ distribution for area 1.

Figure 4 depicts the resulting distribution for density (φ) for area 2. The representative population density distribution for area two is a normal distribution with mean of 0.000402085 and standard deviation of 0.000102536. Figure 5 depicts the resulting distribution for density (φ) of area 3. The representative population density distribution for area three is a normal distribution with mean of 0.000124368 and standard deviation of 3.07317E-05. Figure 6 shows the resulting distribution for density (φ) of area 4. The representative population density distribution for area four is a normal distribution with mean of 0.002208846 and standard deviation of 0.000551396. It can be seen that the density distribution for the area 4 has a denser distribution representative.

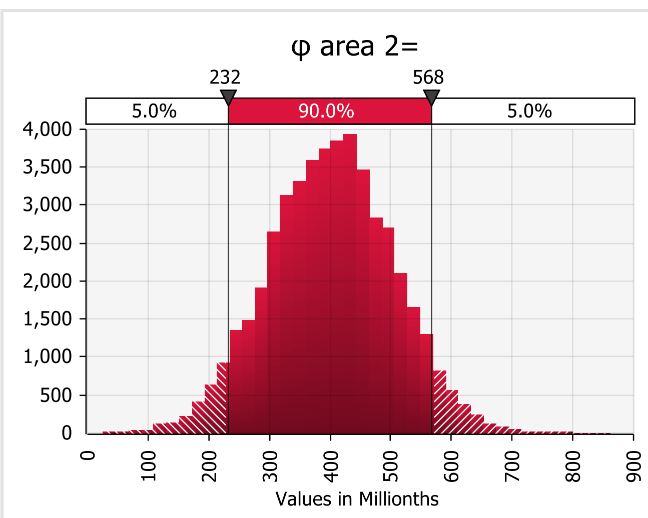

Figure 4. Resulting φ distribution for area 2.

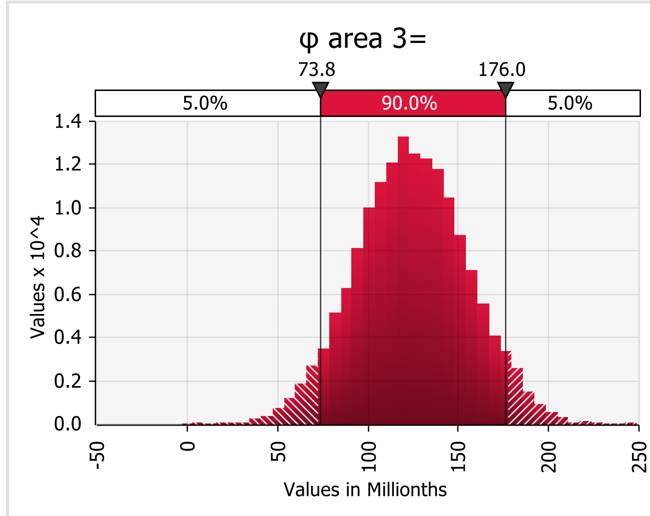

Figure 5. Resulting φ distribution for area 2.

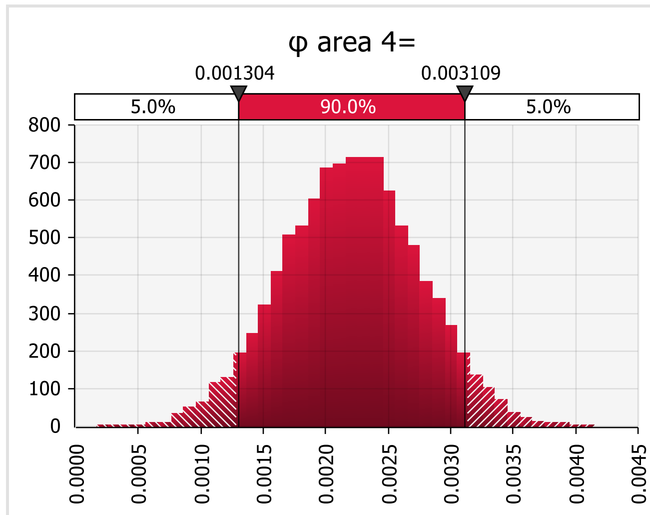

Figure 6. Resulting φ distribution for area 2.

A MCS of Eq. (2), using the aforementioned factors, was run using the Palisade @Risk 7.5. The number of simulation iterations was controlled for convergence of the mean, standard deviation, and 90% percentile simulated values of the SO results of each area. The simulation was run until it reached convergence with 95% confidence and 5% tolerance. The convergence was checked every 600 iterations. The simulation reached convergence at 102,000 iterations. The results of the Monte Carlo simulation are summarized as follows:

- Area 1 (Figures 7 and 8):
  - Mean: 2.53521E-07
  - Mode: 2.64621E-08
  - Median: 1.7822E-07
  - Standard deviation: 6.22557E-07
- Area 2 (Figures 9 and 10):
  - Mean: 9.57806E-08
  - Mode: 9.05201E-09
  - Median: 6.7361E-08

    - Standard deviation: 1.968E-07
- Area 3 (Figures 11 and 12):
    - Mean: 2.94819E-08
    - Mode: 2.86018E-09
    - Median: 2.07374E-08
    - Standard deviation: 6.47009E-08
- Area 4 (Figures 13 and 14):
    - Mean: 5.21982E-07
    - Mode: 4.10386E-08
    - Median: 3.73742E-07
    - Standard deviation: 9.33199E-07

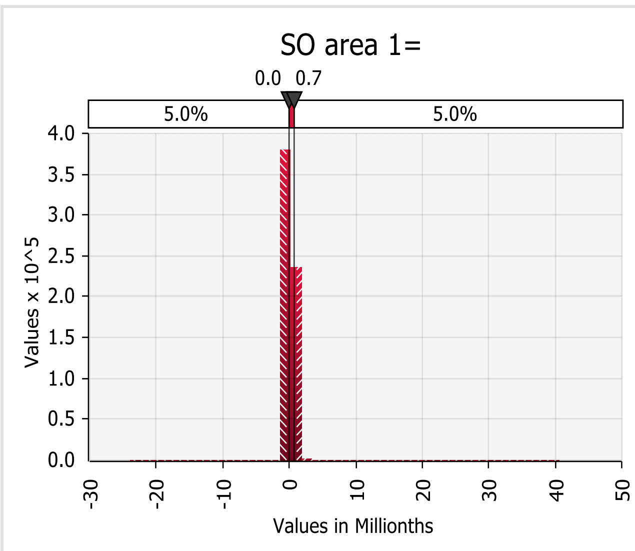

Figure 7. SO result of area 1 from simulation.

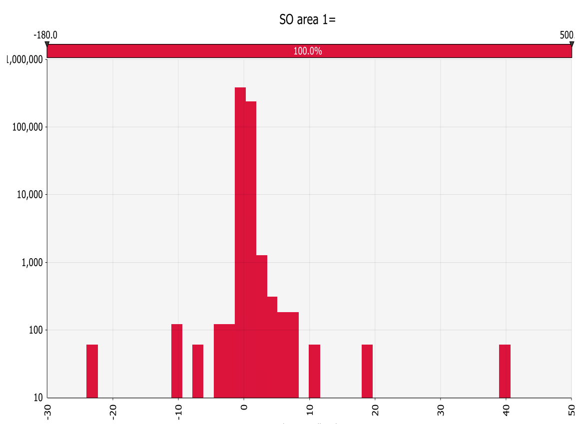

Figure 8. Zoomed in SO result of area 1 from simulation.

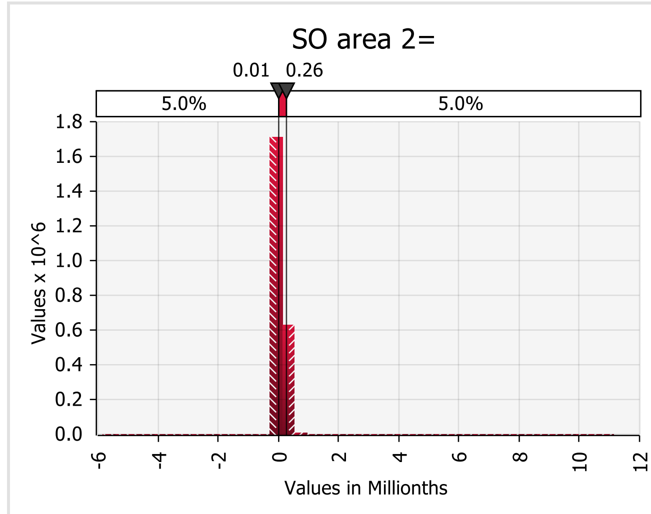

Figure 9. SO result of area 2 from simulation.

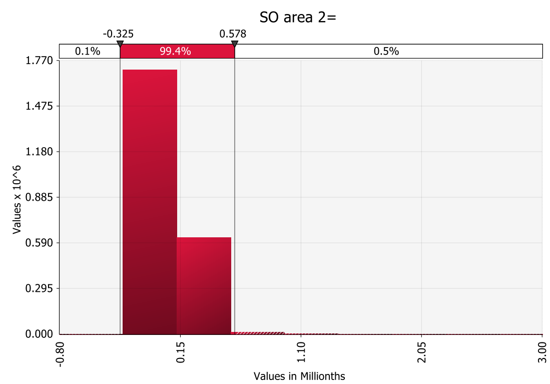

Figure 10. Zoomed in SO result of area 2 from simulation.

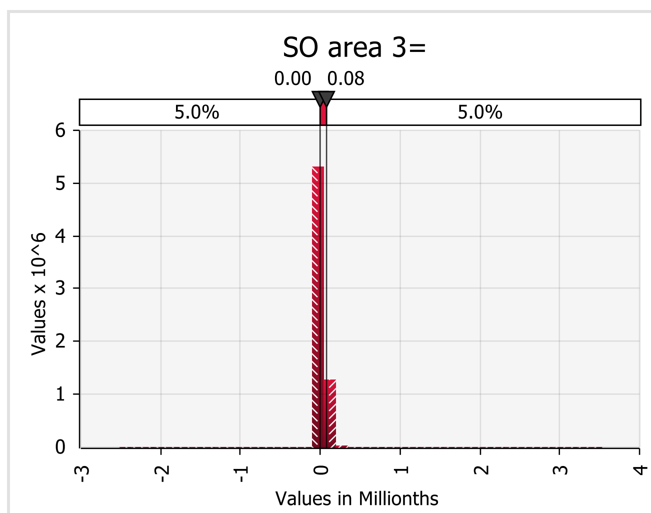

Figure 11. SO result of area 3 from simulation.

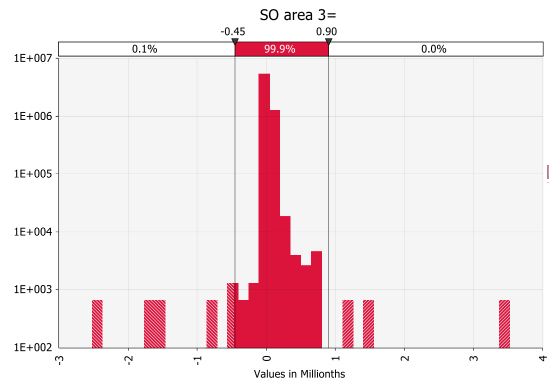

Figure 12. Zoomed in SO result of area 3 from simulation.

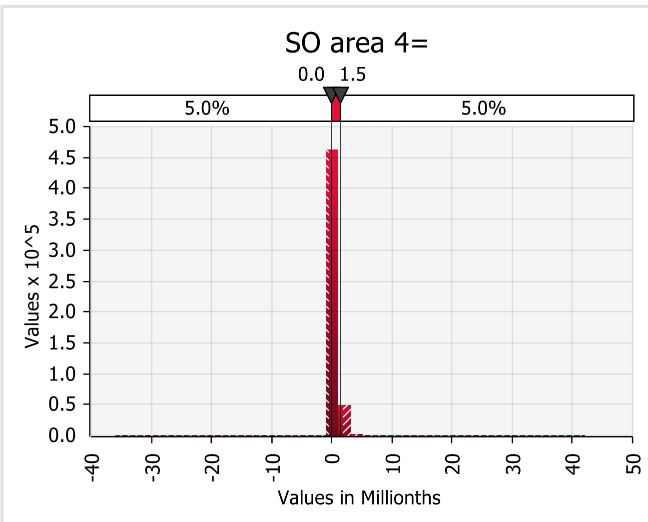

Figure 13. SO result of area 4 from simulation.

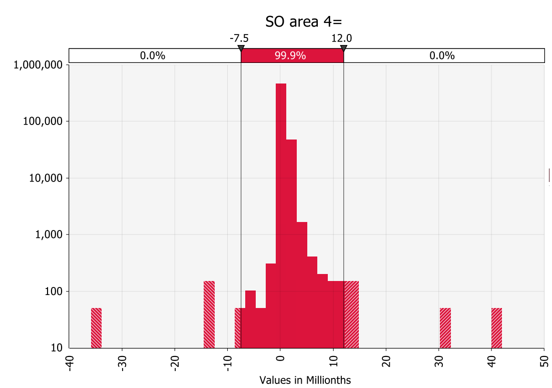

Figure 14. Zoomed in SO result of area 4 from simulation.

Figures 15-18 depict the inputs' impacts on the corrosponding SO output means. It is evident that AL had the most significant impact, followed by the MR and the least impactfull variable is the number of workers in the area. However, it should be noted that this conculusion is based on the assumptions of this study and it should evaluated on a case by case basis.

Figure 15. Inputs effect on SO area 1 mean.

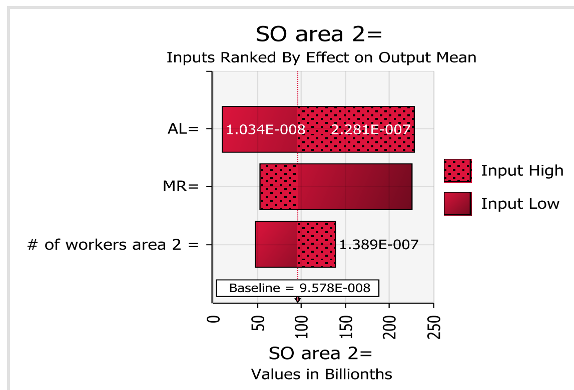

Figure 16. Inputs effect on SO area 2 mean.

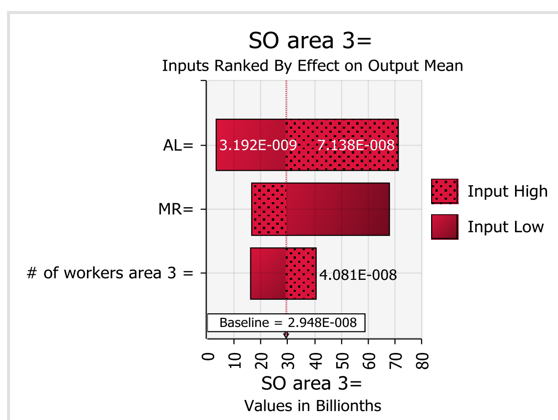

Figure 17. Inputs effect on SO area 3 mean.

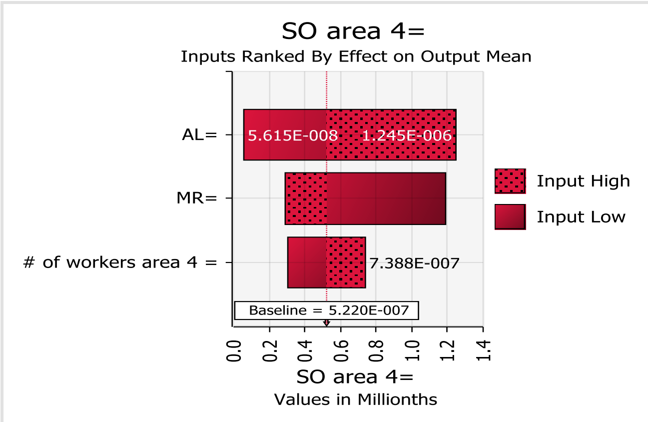

Figure 18. Inputs effect on SO area 4 mean.

Figure 19 shows the changes in the output mean of the SO area based on the variation on of the inputs. It can be seen that the AL and MR have the same imapct on the SO while the number of workers in the area has the opposite effect.

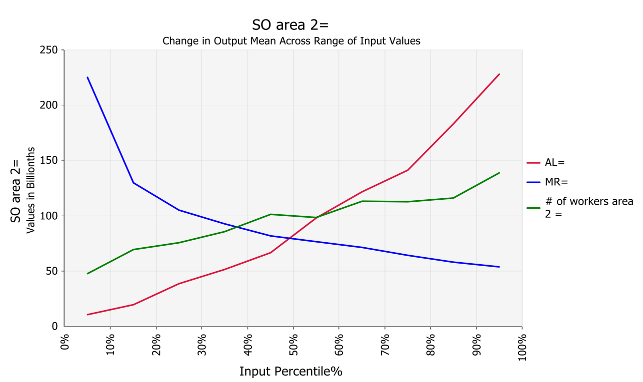

Figure 19. Change in output mean of SO in area 2 depending on variations in the inputs.

B. *Analysis of Qualitative Risks of UAV Flights*

As extensively discussed in Section II, the FAA governs UAVs flights in U.S. National Air Space. Some of the rules and regulations that FAA posed on UAVs flights prohibit UAV flights over general population or simply over people's heads. Using this logic, in Figure 1, there is a need to restrict UAV flights to only areas that are considered safe based on FAA rules and regulations. Consequently, in Figures 2 and 20, the job site is divided into four standalone areas; each safe for UAV flights considering these areas do not contain workers' pathways. These areas are contained between shared workers' pathways or walkways. In order to qualitatively measure the safety of UAV flights in this case study, a qualitative assessment of UAV flights risks, using FAA rules and regulations, is developed. Some of the principles that are used are as follow:

- UAV no-fly zone areas are shown in red. These are the areas that are absolutely forbidden for UAVs to fly over/on due to federal rules. The no-fly zones are considered to be airspace above people's heads.
- The area immediately adjacent to the red areas are shown in orange as it is risky to fly close to a no-fly zone.
- Any existing construction equipment is shown in orange. It is risky to fly over, on or adjacent to this moving construction equipment.
- In this example, there are two tower cranes which, by nature, are constantly moving in three dimensions. It is risky to fly on or close to these tower cranes.

By taking into account of all the above-mentioned facts, a color-coded safety map in Figure 20 illustrates the safety risks of UAV flights based on the qualitative facts. In this figure, green indicates safe flight zones. Red indicates no-fly zones and orange indicates risky flight zones. As shown in Figure 20, all areas of this job sites are considered safe, shows in green, except the areas that are on the direct workers' pathways, which are shown in red as an indicator of absolute no-fly zones, and areas close to red zones or close to construction equipment including two giant tower cranes shown in east and south sides of the under-construction building in Figure 20. It is recommended that UAV flights in orange areas be in discretions of the construction project teams. Construction project teams are advised to make decisions on the safety of UAV flights over orange areas by considering all facts and on a case by case basis.

VI. DISCUSSION AND CONCLUSION

This paper presents qualitative and quantitative risk analyses of UAVs flights over construction job site environments. It is the first known study discussing risks of UAVs flights over construction job sites using a Monte Carlo Simulation as a well-known quantitative analysis and also a qualitative analysis based on FAA rules and regulations. The qualitative method proposed in this research uses UAV lethal area, failure rate, also referred to as Mishap Rate, and population density as the main factors to quantify the direct risks associated with UAV flights. The model is tested in a case study; an under-construction building at the University of Florida's campus. Monte Carlo Simulation is used as the computation technique to run the simulation of the proposed model using the case study characteristics as inputs. Different probabilities are given for personnel on job site, UAV size, which is used for finding the lethal area, and mishap rates. The results show that the safety objectives, expressed in terms of fatalities per million flight hours, vary in Areas 1 through 4. Areas 1 and 4 have the highest median of safety objectives by 1.7822E-07 and 3.73742E-07, respectively. These numbers mean the expected fatalities for a UAV flight over these areas are 1.78 per ten million flight hours for Area 1 and 3.73 per ten million flight hours for Area 4. Based on Clothier and Walker [23], the general aviation industry fatality rate is restricted to one fatal incident in one million flight hours. While it is not truly

Figure 20. A color-coded map showing the qualitative risks of flying UAVs in a construction job site, where green represents the minimum risk, orange represents the medium risk and red represents high risk or no-fly zones.

accurate to propagate the fatality rate of the general aviation industry to the UAV industry, authors use the general aviation industry as a reference to compare the risks due to the lack of data on qualitative risks of UAV flights.

By comparing the simulation results to the general aviation industry fatality restriction rate, which is one fatality in a million flight hours, it appears that in the case study analyzed in this paper, most areas have lower than normal fatality risks of flights. It is worth noting that ultimately is up to construction managers or safety officer to utilize these findings and decide on the appropriateness of UAV flights on this construction site.

The FAA rules and regulations prohibit UAVs to fly over peoples' heads, over or close to airports and set specific guidelines regarding UAVs operations. By combining FAA rules and guidelines and safety needs of UAV flights in construction environments, such as higher risk of UAV collision in proximity of tower cranes, a qualitative color-coded safety map is generated that shows the relatively safer areas for UAV flights, using green, compare to medium UAV flight risks areas, with orange color, and no-fly zones, or the highest risks of UAV flights zones with red.

The presented qualitative and quantitative analyses help construction project managers, construction safety managers, site superintendents and insurance companies to make informed decisions, based on actual data, regarding the safety of UAV flights using specific temporal and spatial data. These models will also enable different stakeholders to detect, explore and address the risks of UAV flights in construction job site environments, which will help the construction industry to better manage the safety of UAV flights.

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Cybersecurity and the Evolution of the Customer-Centric Service Desk

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***Abstract* – Cybersecurity is now seen as a central function of the modern IT Service Desk. This article examines two case studies of Helpdesk or Service Desk operations in different technology eras, and highlights the recent emergence of Cybersecurity as a critical area of Service Desk responsibilities. The article profiles the Helpdesk operations at Glaxo Pharmaceuticals in the late 1980s and the Service Desk functions at the University of Gloucestershire in 2019. Comparative analysis shows that whilst the range of technologies requiring support has increased markedly, this has been counter-balanced somewhat by the emergence of standards and dominant products in many technology categories. Cybersecurity, however, has emerged as a key concern that permeates all fields of Service Desk support. It also finds that the role of the end-user has evolved significantly in a rapidly changing technology landscape.**

Keywords – Cybersecurity; Service Desk; Helpdesk; customer-centricity; office systems; personal productivity tools; business systems; end-user computing.

I. Introduction

The advent of the personal computer in the 1980s and the subsequent widespread use of the Internet and mobile technologies ushered in a revolution in corporate computing that has required a step-change in end-user support and Service Desk capabilities [1]. Amongst these new capabilities and competences, Cybersecurity has become a key element of Service Desk support, and its significance to corporate sustainability is only likely to increase in future years. An enterprise security review recently concluded, "Cybersecurity now lies at the very heart of the corporate and public sector agenda" [2] and the complexity and far reaching nature of Cybersecurity is well illustrated by the multiple lawsuits being pursued against Apple Inc. As reported in the Washington Post, FaceTime (Apple's video chat application) "suffered a security glitch that enabled users to 'eavesdrop' on conversations and see individuals through their iPhones without detection" [3]. The bug was fixed only two weeks after its discovery, resulting in concerns around both personal and business security. Another pertinent example surfaced in July 2019, when it was revealed that British Airways faces a £183m fine over a security breach that occurred in 2018 - a record fine for a data breach and the first to be levied under the General Data Protection Regulation (GDPR) in the UK [4].

Back in 1988, there was virtually no use of the Internet, portable computers were in their infancy, there were no mobile phones or tablets, and the issues surrounding Cybersecurity were very different. Although the personal computer (PC) had broken through to become the main desktop device in the more technology advanced organisations, local area networks were just being introduced and MSDOS was the main PC operating system in the pre-Windows age. Many of the mainstream corporate systems were bespoke (often in 3G languages like COBOL), and the main packaged software products like the SAP and Oracle Enterprise Resource Planning (ERP) systems were just starting to be taken up by the bigger corporations.

Support for such technologies is a key issue in nearly all organisations today, and this article examines the origins and evolution of end-user computing and support functions over the past three decades, and focuses specifically on the requirements to ensure effective Cybersecurity. It features two case studies. First, Glaxo Pharmaceuticals, which was an advanced technology user and was seen as a leader in its rapid uptake of PC applications in the 1980s [5]. The second case study concerns the University of Gloucestershire (UoG) in 2019.

This introductory section is followed in Section II by a brief discussion of the background to this research and the case study methodology, and sets two research questions. Sections III and IV discuss the two case studies and section V then focuses on Cybersecurity and suggests an outline checklist for Service Desk monitoring of Cybersecurity issues. Section VI addresses the two research questions. Finally, Section VII summarises the research findings featured in this article.

II. Background & Research Method

IT services are key in ensuring the efficiency and agility of business processes, and the importance of a successful Helpdesk or Service Desk in supporting corporate performance is generally accepted. As early as 1992, Bridge and Dearden [6] noted "the quality of Helpdesk operations can be improved by the provision of knowledge to front line Helpdesk operators" and that "this could only be done effectively if AI technology is used". This early study of Helpdesk operations proved prophetic, as Helpdesks have evolved to meet the changing demands of end-users and have used increasingly sophisticated support systems. Existing literature also highlights the increase in the range of technologies that Helpdesks are required to support. Gonzalez, Giachetti and Ramirez [7], for example, note that the average number of information technologies supported by central support functions has increased from 25 to 2000 in the current millennium. Sood [8] recently noted, "The cross-functional nature of its operation means the help desk directly impacts productivity and is an essential part of what enables an agency to meet its stakeholder needs".

One of these needs is to ensure protection against hackers and outside interference or unauthorized access to an organization's systems and the data they contain. This is normally termed "Cybersecurity" which is defined by the National Institute of Standards and Technology [9] as "the ability to protect or defend the use of Cyberspace from Cyber-attacks". More specifically, the Economic Times [10] see Cybersecurity as "the techniques of protecting computers, networks, programs and data from unauthorized access or attacks that are aimed for exploitation." The main areas covered in Cybersecurity are:

- *Application Security*, which "encompasses measures or counter-measures that are taken during the development life-cycle to protect applications from threats that can come through flaws in the application design, development, deployment, upgrade or maintenance."
- *Information Security,* which "protects information from unauthorized access to avoid identity theft and to protect privacy."
- *Disaster recovery planning,* which is seen as a process that "includes performing risk assessment, establishing priorities, developing recovery strategies in case of a disaster. Any business should have a concrete plan for disaster recovery to resume normal business operations as quickly as possible after a disaster."
- *Network security,* which encompasses "activities to protect the usability, reliability, integrity and safety of the network. Effective network security targets a variety of threats and stops them from entering or spreading on the network" [10].

Effective and robust Cybersecurity requires measures based around "three pillars: people, processes and technology" [11]. This approach can help organisations "defend themselves from both highly organised attacks and common internal threats, such as accidental breaches and human error" [11]. As a Chief Information Security Officer (CISO) recently noted, "by aligning security with the technology function, it is considered a technology problem to fix, but what we know now about security is that it transcends many different frontiers of business, that it's a people, process and technology problem to fix" [2].

People: All members of staff and (in the context of a university) students need to be aware of their role in preventing and reducing Cyber threats, and specialist Cybersecurity technicians must remain abreast of new developments, with new skills and competencies to mitigate and respond to Cyber-attacks.

Processes: Processes are crucial in defining how the organisation's activities, roles and documentation are used to mitigate the risks to the organisation's information. Cyber threats change quickly, so processes need to be continually reviewed to be able to adapt with them.

Technology: By identifying the Cyber risks that an organisation faces, the necessary controls can be put in place. Appropriate technology can be deployed to prevent or reduce the impact of Cyber risks, depending on risk assessment and what is considered an acceptable level of risk [11].

This article looks at two case studies of relevance, spanning a thirty-year time gap. The case study is a widely used methodology within business research and Bryman and Bell [12], for example, argue that the case study is particularly appropriate to be used in combination with a qualitative research method. A case study facilitates detailed and intensive research activity, usually in combination with an inductive approach as regards the relationship between theory and research. Saunders, Lewis and Thornhill [13] argue that case studies are of particular value for explanatory or exploratory investigation.

Data collection was pursued through participant observation and action research. One of the authors worked at the first case study company (Glaxo Pharmaceuticals) as IT Trainer and then End-User Computing manager in the 1984-88 period. Some of the observations included here were discussed in research publications at the time [5] [14], and these have been used as secondary sources of material. The other author has worked on the IT Service Desk at the second organization (UoG) and thus has first-hand experience of the technologies deployed and the Service Desk operations. There are thus multiple sources of evidence, which as Yin [15] suggests, is one way of increasing the construct validity of case studies. At UoG, this includes participant observation and a number of internal reports and policy documents, particularly those concerning Cybersecurity.

Within this context, this article addresses two research questions (RQs):

RQ1. How have the support requirements of Helpdesks and Service Desks evolved over the past thirty years?

RQ2. How has the Service Desk developed in response to the need for Cybersecurity?

III. Case Study 1: Glaxo Pharmaceuticals 1988

Overview: In 1985, the European shipment of PC workstations overtook shipments of simple terminals (i.e., video display units and keyboards, with very little processing power), with computer users taking advantage of new word processor, spreadsheet, graphics, email and database applications running on their PCs. Within this change environment, Glaxo Pharmaceuticals saw a rapid increase in the use of PCs, which transformed the nature of computing within the company. In excess of 1300 PCs were installed in the company's four sites at Greenford (London), Barnard Castle (County Durham), Ware (Hertfordshire) and Speke (near Liverpool). This expansion reflected the dramatic growth and improvement in PC-based office systems during this period. However, in 1984, office systems were clearly a function of the HP3000 mini-computers, there being over a thousand users of these office systems in Glaxo, over 600 of which were electronic mail users. There were just a few PC-based users of spreadsheets in the sales, marketing and market research areas. By 1988, one in four staff had a PC, and of these, six out of ten had a spreadsheet, four out of ten had a graphics package and a word processor, and three out of ten had a database package. The use of mini-computer graphics modelling and word-processing had virtually disappeared, but electronic mail remained a function of the Hewlett Packard mini-computers, there being over 2,500 users, a fourfold expansion since 1984.

Word processing and desktop publishing: In the period 1984-88, word-processing experienced several phases of growth. In the two years after 1984, the company standardized on one main word processing system (HPWord), based on an HP mini-computer for all secretarial/office staff. Then, in 1987-88, as the PC became the standard desktop machine rather than the terminal, users were transferred to a PC-based version (PCWord) of the software, thus minimizing the need for retraining. Then in 1988, the company embarked on a further change that would see the introduction of a more sophisticated word processor as the standard for secretarial use. This was in part driven by the well-publicised benefits of using the so called "desktop publishing" (DTP) packages, which required a skill level normally beyond that of the average secretary, and which also required specialist workstations (an 80386 chip, and a PostScript-compatible printer) if acceptable performance was to be achieved.

TABLE I. END-USER COMPUTINGE SYSTEMS AT GLAXO PHARMACEUTICALS 1988

End-user system name	**Software**
Electronic faces folder	DB3+/Tencore
Medical records	DataEase
Unpublished journals	DataEase
Label reconciliation	DataEase
Materials requisition	RBase 5000
Medical terms dictionary	Custom-built in PASCAL
Accident records	DataEase
Project engineer management	DataEase
Media scheduling	DataEase
Planning & budgeting	DataEase
Action reporting	DataEase

This resulted in the introduction of only two desktop publishing workstations (running PageMaker and/or Ventura software packages). However, it was expected at the time that the standard document processing software available to secretaries would come to include some DTP functions such as graphics and scanned image importation, and this is indeed what happened. It was thought that a move to the type of mid-range product in the word processing to DTP spectrum (such as the Lotus Manuscript or Advancewrite Plus software packages) would be beneficial. The coming of Windows as the standard operating system and the gradual dominance of the Microsoft Office products was not envisaged at that time.

Databases and spreadsheets Databases are possibly the most powerful end-user tools of all the functional "off- the-shelf" packages, while spreadsheets are the most commonly used. A PC survey carried out at Glaxo in May 1988 found that for every PC database system written by the company's Information Management Division (IMD), end-users had developed three systems for themselves. The PC systems developed by IMD at the request of end-users is shown in Table I. Authorisation for these systems was done on an *ad hoc* basis, and approval for resource allocation from higher management levels was not required. A number of different spreadsheet packages had been tried by end-users, but Lotus 1-2-3 was the most commonly used.

Graphics packages: Graphics packages were not as common as word processors, but the two were increasingly used in unison as standard secretarial software. They were used mainly for departmental reports and presentations. The data was still input manually for the most part, but electronic transfer into graphics packages was on the increase as integration with mainframe databases and other office systems improved. This was to be a forerunner of the wider integration and consolidation of office productivity tools that occurred in the Microsoft era. By 1988, the main graphics package used was Freelance or Freelance Plus, which was then from the provider of the Lotus 1-2-3 spreadsheet, ensuring ease of data transfer between the two packages.

Electronic presentations systems and presentation design software: This was a significant end-user computing activity. There was a range of software packages available for electronic systems, including PictureIt and Freelance Plus, running on the so-called "IBM compatible" PCs. PictureIt enabled the user to design bar, pie, line, organization and word charts in a range of pre-determined formats. It was extremely easy to use and yet contained sufficient variety to facilitate the design of a reasonable presentation. This was particularly useful for senior management and the sales and marketing functions.

For more specialised needs, Freelance Plus was used. This was a freeform drawing package, with a range of icon libraries that could be combined with PictureIt images. Graphs could also be imported from other software packages (including Lotus 1-2-3 and Lotus Symphony). Standard 80 column/25 line text screens could also be converted to VideoShow format and edited using VIP.

The VideoShow presentation system was made available to be taken out on loan from the IMD, and each of the four sites had at least one of these machines. Having prepared the presentation with software running on the PC, this was then saved to "floppy disc" and run on the VideoShow presentation system. These presentations could be given to a large audience via a projector (e.g., Barco Data 3 or Electrohome ECP 2000) or a colour monitor for smaller audiences. The wide range of colours available (1,000) as well as the range of formats available made this a convenient way to present material suitable for a 35mm slide presentation. The obvious advantages included the portability of the presentation (one floppy disc could hold as many as 200 images) and the fact that the presentation was always in the correct order, the right way round and there were no focusing problems.

Computer based training (CBT) packages: From 1985 onwards, approximately 30 CBT packages were developed by IMD using the Tencore authoring language [16]. Most of these were for sales and marketing training, and their support and on-going enhancement and update constituted an element of PC systems support at the time.

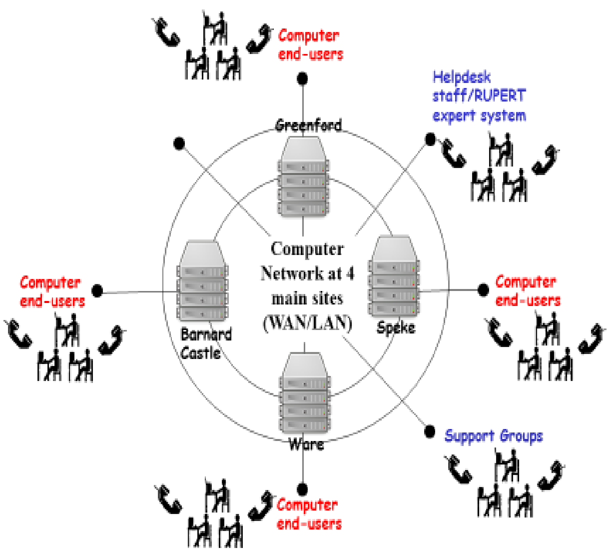

Figure 1. The Rupert Helpdesk system: interaction with end-users and support groups.

The Helpdesk function: The Helpdesk was centralized at the company's Greenford site, but had links to support staff in the company's three main manufacturing plants at Ware, Barnard Castle and Speke (Figure 1). By 1988, IMD had developed its own in-house fault logging diagnostic system, built using an expert system shell (CASSANDRA). This system was known as "Rupert" (Resolves Users' Problems Expertly).

The Helpdesk had hitherto been manned by a senior network analyst who used his expertise to help solve users' problems. Rupert encapsulated some of the experts' knowledge and was able to apply it to users' problems. By asking a series of questions, Rupert could home in on a problem. In some situations, it could take action such as aborting a users' session, disconnecting a terminal or asking the user to perform some action such as pressing a key etc. In other cases, where Rupert was unable to provide a full solution, the call was passed on to the support group, which, in Rupert's judgement, would be best placed to deal with the problem.

The support groups were still in the main geared to helping users of the company's wide range of bespoke transaction processing and reporting systems for their manufacturing and financial functions. These were mainly written in COBOL or PASCAL, and the analyst-programmers of the day doubled up as support staff to help end-users. Indeed, for the main manufacturing system (known as "MENTOR"), there was a programme of courses run on the four sites on test machines on which the main manufacturing systems could be simulated. There were three main support groups for the main corporate business systems and a fourth for office systems and end-user computing. The main business systems were run on Hewlett Packard mini-computers at the four sites linked by a wide area network, and there were a number of test and development machines.

It was in these support groups that security issues of the day were managed and problems resolved. The main concerns were less about Cyber threats from third parties, but rather about human error corrupting data. There were particular requirements in the pharmaceuticals industry in relation to Good Pharmaceutical Manufacturing Practice (GPMP), notably stock traceability in the event of damaged or defective products, and process validation, which required high levels of access control and back-up procedures, above all in the MENTOR suite of programs. The concepts of application and information security, and disaster recovery planning, were in evidence in what was an advanced blue-chip company; and network security was of paramount importance in ensuring the transfer of data and information via the WAN that linked the company's four sites.

More generally, the Rupert Helpdesk system produced fault statistics, which helped IMD to identify problem areas and thus continue to improve the service given to users. The major benefits of Rupert to the company were:

- its role as a training aid for new Helpdesk staff;
- the ease with which new knowledge could be added to the system;
- the time taken to resolve user problems was halved;
- the improved image of IMD in the rest of the company;
- the better statistics it provided about user problems.

The last two benefits could probably have been obtained from any Helpdesk function and fault reporting software. However, Rupert's excellent user interface made this a very successful application of expert system techniques. It was envisaged that the system would eventually be the focal point of a comprehensive network management system.

IV. CASE STUDY 2: UNIVERSITY OF GLOUCESTERSHIRE 2019

Overview: UoG is located across six sites within Cheltenham and Gloucester with 20 professional departments. The Library, Technology and Information Service (LTI) department provides supports for both staff and students, particularly for teaching and learning, along with the provision of appropriate training and skills development. The University has over 1,500 staff, most of which are computer users, and approximately 10,000 students, who use a range of applications on University equipment in labs and classroom environments. The IT Service Desk is located within LTI and provides full support for staff in University hardware, communications and software solutions. Support for students encompasses Office 365, assignment submission, the Moodle learning management system, and a range of IT guides accessible via MyGlos Help (a web portal guidance page which helps student to search for guidance and information).

TABLE II: MAIN BUSINESS SYSTEMS SUPPORTED BY UOG LTI

System	Description
Sunrise	IT application to manage enquiries from students and staff
SITS Student Records	SITS is a student records management system used to store, administer and manage all aspects of student information from initial enquiry and application through to degree congregation. A configurable package from software provider Tribal.
ResourceLink	ResourceLink is an integrated HR and Payroll software package.
Agresso Finance	A global accounting system from software provider Unit4.
Moodle	Moodle is a free and open-source learning management system written in PHP and distributed under the GNU General Public License.

Office productivity tools and end-user computing: Microsoft Office 2016, Adobe, SSRS, SPSS, and NVivo are the main packages that are increasingly used as standard on a daily basis. SSRS (SQL reporting) is mainly used for departmental reports, whilst SPSS and NVivo are only used for teaching and research purposes, and PowerPoint (part of Office 2016) is the main package used for presentations. There are many different packages on different machines, depending on department needs. For example, there are 150 graphics package users in the Departments of Art and Design and Landscape Architecture. The operating system for the PCs is currently Windows 7, although a University-wide upgrade to Windows 10 is currently being rolled out. The University email system is based on Microsoft Office 365 and hosted externally. The University supports Office apps such as Skype for business, Outlook, OneDrive, and uses the international roaming service called Eduroam to provide Wi-Fi connectivity. Eduroam allows UoG users to login at any participating institution using their UoG login name and password. Eduroam also allows users from any participating institution to login to UoG using their local login name and password. LTI use Gmetrix to provide Microsoft Office training to both staff and students. UoG supports staff and student research projects with SPSS and NVivo.

As regards telephony, the internal telephone system (an Avaya IP phone system providing telephony for all the University campuses and the majority of the student halls of residence) is complemented by a number of exchange lines direct from the BT exchange. These are used for alarm lines, swipe machines for debit and credit cards, and payphones around the University and in halls of residence. LTI are responsible for managing mobile phone services, which are coordinated through a centralised agreement with Vodafone. The University will provide support for equipment and software, which is procured by the University, but does not support mobile phones, tablets or other equipment purchased by staff or students themselves. Nevertheless, the frontline support teams will endeavour to help students with their own devices if they can (e.g., to reinstall software or attempt data recovery), but they will not attempt to fix any major hardware or mechanical problems.

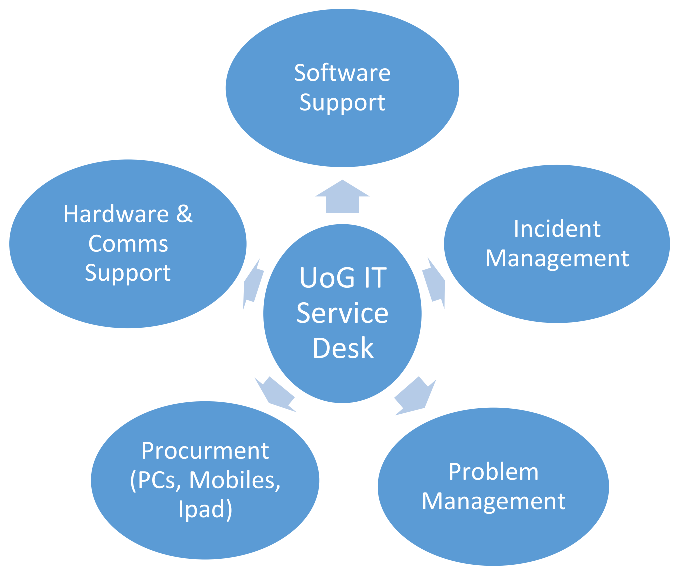

Figure 2. Main operational functions of the UoG IT Service Desk 2019.

UoG Main Business Systems: There are about 60 business systems running across the University, including Sunrise, SITS Student Records, ResourceLink, Agresso Finance and Moodle (Table II). All of these are now supported by LTI, although some started as departmental end-user systems prior to the centralisation of IT support within the University and the imposition of certain policies and standards. Many of these systems are administered by end-users who undertake data maintenance and general support tasks. The SITS student records management package is one of the University's core systems, and the system is upgraded regularly with modifications and new releases from the software supplier (Tribal). These are tested and implemented in the test environment by the SITS users. When the software has been tested thoroughly and approved, a change control is raised which then goes to a change control board, who will approve or reject the change. New developments are driven by the University's business and legal requirements.

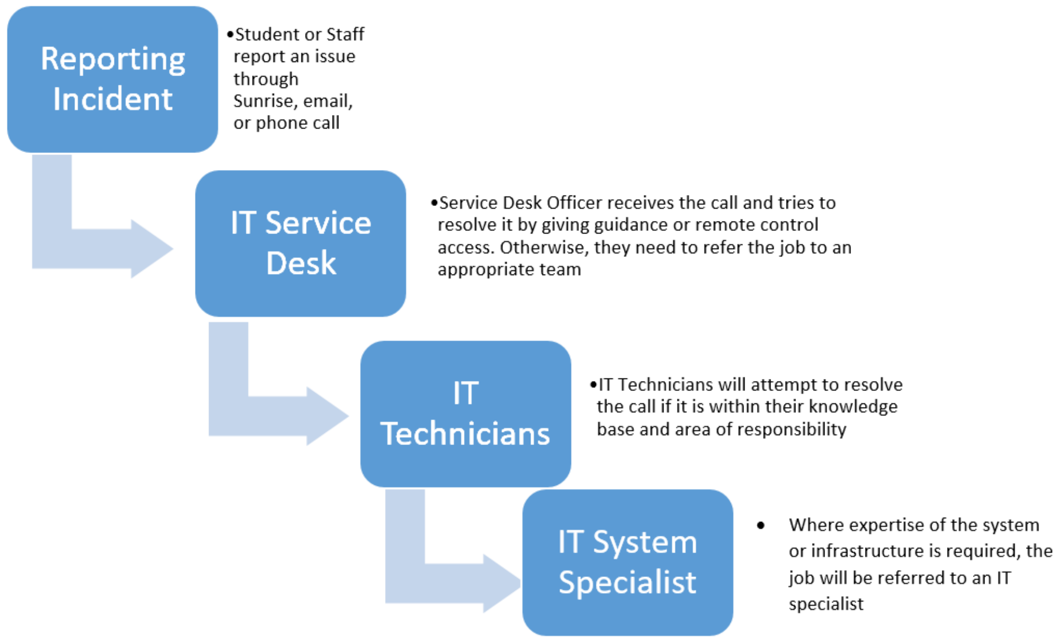

Figure 3. Incident Tracking by UoG IT Sevice Desk 2019

The general policy for the procurement of new software applications is that they should be based on web-enabled technologies that will assist in the development of a University-wide Managed Learning Environment (MLE). This principle guides procurement when the University has the opportunity to replace business systems through the annual IT capital programme.

UoG IT Service Desk functions: Sunrise is the main system used by the LTI staff to manage enquiries from students and staff. In addition, any enquiries received via the MyGlos Help Portal are redirected to the appropriate team. Different versions of Sunrise have been used by the University since the year 2000, but all with the same backend. With the latest version of this system, keywords can be used to select the problem categories and the problem is automatically assigned to appropriate support personnel.

The IT Service Desk performs a number of functions (Figure 2). It has the responsibility for all user account management as well as giving access to all University business systems such as Agresso and SITS. LTI is responsible for providing the basic "image" (i.e., software footprint) for all staff and student devices. A minimum of between 4-6 weeks is allowed to enable a thorough evaluation and testing of any new software application.

Figure 3 shows the escalation of a call through different levels of service expertise depending on the complexity/specialism of the problem reported. This systematic approach to tackling problems, combined with the application of dedicated human resources to solving Service Desk enquiries, has contributed to a significant improvement in response times and a more efficient IT service for the University's staff and students.

Support teams across the university's four main sites use IT Service Desk tools and the Sunrise support system. The IT Service Desk tools are an integral part of the Sunrise system, and were developed as a bespoke, standalone system for UoG. Some of its main functions are:

- Password reset
- Unlock accounts
- Create guest login for externals
- Provide access to shared drives
- Deploy software
- Change voicemail passwords

LTI uses the Sunrise system to log calls, update the call, and transfer the call to the appropriate support team. Service Desk officers have access to all communications across the University by searching for the Incident number (ID), call details, surname, forename, category, hub area, open date, network logon, global summary, priority, escalation level, assigned group, and first time fix. The call needs to be logged under the name of the person that reported the enquiry, which can be logged by network logon (staff number) or forename and surname. The category is selected based on the enquiry;

TABLE III.CYBERSECURITY CHECKLIST FOR SERVICE DESK MONITORING

	People Skills & Competencies	Process Requirements	Technology Deployment
Application security	• Respect for user privacy and confidentiality (access to sensitive data) • User systems knowledge • System administration skills and responsibilities • IT staff communication skills	• Systems documentation, user guide policy and procedures • Knowledge management (consistent terminology and definitions, amending and updating data) • Systems maintenance and update controls and procedures	• Authentication and access control in main business systems
Information security	• User awareness of criticality of data and information • Cybersecurity awareness programmes and briefings	• Data integrity policies and procedures • Information security recognized and managed as a continuous process	• Physical security mechanisms to protect assets and workplaces from unauthorized access • Data accuracy validation controls
Disaster recovery planning	• Clear management responsibilities for different Cyber threats	• Prevention and detection procedures • Threat and risk management processes to support vulnerability assessment • Incident tracking system and response plan	• Database recovery and back-up systems • On-site/off-site storage options
Network security	• User and IT professionals' awareness of Cyber threat via the networks. • Network administrator role with Cybersecurity responsibilities	• Network security controls and procedures, including password security • Control of network administration rights and privileges	• Firewall, antivirus and encryption programs for all physical and virtual servers, workstations, laptops, tablets, phones and mobile devices. • Appropriate Virtual Private Network utilization • Email server configuration and intrusion detection software • Resilient network architecture

for example, if someone reports an issue with email, Service Desk officers can search for emails and pick the correct category. The use of keywords and categories ensures that an enquiry is managed by the most appropriate team. Once the category has been selected, the system will automatically pick the first line team and referral team appropriate to the job.

All the operations of the Service Desk are now impacted by Cybersecurity issues, as has been highlighted by Whitman and Mattord. They note that technology has permeated every facet of the business environment in the last 20 years and that "the business is no longer static; it moves whenever employees travel for office to office"; and therefore "the security of the organisation also depends on the implementation of a multi-layered system" [17].

V. TOWARDS A CYBERSECURITY CHECKLIST FOR SERVICE DESK MONITORING

The Service Desk thus has a key role to play in the monitoring and reporting of Cybersecurity and this section draws together the different operational areas supported by the Service Desk at UoG to set out a rudimentary checklist for Cybersecurity (Table III). Cybersecurity is being marketed as a new software category, including Security Information Event and Management (SIEM) systems and Security Orchestration Automation and Response (SOAR) systems. These are in essence sophisticated reporting tools, sometimes involving machine learning, advanced statistical analysis and analytics software. Rapid7 [18], for example claim "security orchestration and automation helps teams improve their security posture and create efficiency—without sacrificing control of important security and IT processes". However, to be of value, they still require the critical underlying data, and the "nuts and bolts" skills and competencies, processes and technologies that the Service Desk can monitor and help ensure are in operation to support the organisation's Cybersecurity. Once these building blocks are in place, then SIEM and SOAR systems can be introduced to provide overall automation and control.

an important competence for support staff. Confidentiality of data access is another important issue that is supported by UoG policy on data breaches, which allows recourse to relevant law enforcement agencies when appropriate. Technology related elements include Anti-Malware policy and associated software to protect the servers and workstations. UoG currently uses Sophos Anti-Malware.

TABLE IV. CYBERSECURITY CHECKLIST: DRILLDOWN DETAIL

Application Security: People Skills and Competencies
• User privacy and confidentiality (access to sensitive data) The concept of privacy is something all users must recognize and respect. In particular, sensitive data contained in business systems should not be divulged to other users or organisations unless authorized. • User systems knowledge System users need to have appropriate levels of knowledge to be able to control and manage the data in a secure way. All users should be clear about their responsibilities, and how systems operations should be completed. • System administrators and super-users Main business applications need systems administration and maintenance and this is increasingly located in end-user departments, requiring appropriate skills, knowledge and responsibilities. Super-users with expert knowledge of how an application works is another role often located in the user department, which may be vital in a disaster recovery or Cyber-attack context. • IT staff communication skills Service Desk staff and other members of the IT team need the communication and vocabulary skills to explain technical issues in non-technical terms. This is important in explaining Cyber issues and may be critical in taking appropriate action in the event of a Cyber-attack.

In terms of Application Security, as defined in Section II, UoG has set up clear access control policies for its users in order to establish the rules, which govern the use of the University's accounts. These policies apply to all students and staff and to all of the University's IT systems, irrespective of how they are accessed. Staff receive privileged access, based on their role and the need for systems access. These People related issues (Table IV) are complemented by policies setting out related Processes, notably for software documentation, user guides and associated procedures. Technology measures include password authentication and systems audits and logging capabilities.

As regards Information Security, Meyers [19] has observed that most security breaches occur at user level, and result from human actions. This has helped shape UoG policy, providing basic security awareness to all users and educating staff and students on, for example, Pishing emails, spam collection etc. A recent survey of Cyber awareness training [20] found that only 11% of organizations continuously train employees on how to spot Cyber-attacks, 24% admit to monthly training, and 52% perform training only quarterly or once a year. The report concludes, "Humans can be either a first line of defense, or the first line that Cybercriminals seek to exploit when they attack an organization. Their behavior and the culture you influence greatly impact the effectiveness of your overall Cyber resilience strategy" [20].

The ability to communicate technical issues to non-technical people in a clear and effective manner has become

If the anti-malware software finds a problem it automatically sends an email to designated members of the First Line Support Team as well as specific second line support staff (e.g. the Information Security and Cyber Developer). With portable devices, there is a greater risk of loss, or infection from the malware, and UoG register all such devices to an accountable owner who is made responsible for security issues. All relevant UoG security policies are applied to these devices to provide protection against unauthorised use.

For Disaster Recovery planning, UoG has set out the rules to govern the ways in which the university makes copies of the data held within its various IT systems. In the event of data loss, caused by an 'incident' (major or minor), data can be restored from the back up and normal service can be resumed. Such 'incidents' include systems crash, ransomware attacks, natural disasters (fire, flood) and catastrophic failure. Processes are in place to identify and recognise the problem, make an initial assessment and communicate the issue to all users. Identified managers are responsible for identifying the nature of the incident, point of origin, determine the intent and identify systems compromised. LTI managers must evaluate the solution and monitor it to determine the outcome. Backups for compromised systems may be used and managers need to review and report on the incident with recommendations for future reference. The technology used for back-up operations does not provide archiving or permanent storage. The storage of data according to specified retention schedules is achieved through management of storage within the online systems. All data held within the Storage Area Network, the virtualised guests and the network file stores is backed-up daily. Initially these back-ups are stored on disc and then transferred to tape. At regular intervals, the tapes are removed to secure storage areas. Both the discs and the tape library are housed separately from the 'live' data, and back-up tapes are encrypted to safeguard data.

Network Security overlaps several of the policy and technology elements discussed above. IT Administrators have specific access rights to the networks and are responsible for ensuring appropriate business continuity measures are in place to protect against events, which might otherwise result in loss of service. Default passwords must be changed the act of changing password is recorded. The effective management and integrity of the networks is supported by firewalls and anti-malware software.

VI. Discussion

This section draws on the case study material discussed above to address the research questions set out in section II.

RQ1. How have the support requirements of Helpdesks and Service Desks evolved over the past thirty years?

Thirty years ago, the need for IT support in major organisations were somewhat different from those of today. There was no significant use of the internet and very few mobile phones or laptops. There was no Windows - MSDOS was the main operating system for PCs. There was no SKYPE, no viruses and no Wi-Fi, but Intel chip-based PCs had established themselves in most organisations and hard-wired LANS linked them to server PCs and mini-computers. Most business systems were bespoked in-house – the age of integrated packaged software was just around the corner.

However, despite the expansion in the range of technologies that Service Desks are now called upon to support, there was arguably more variety in the range of products that needed supporting in each technology category. For example, the Glaxo Helpdesk supported five different word processors and several spreadsheets and graphics packages. The market was still evolving with many competing products and no obvious standards. Presentation graphics systems and videoconferencing also needed support, along with bespoked computer-based training packages in the era before on-line help functions for many software products.

There is now a greater range of technologies to support, but there are clearer standards and more obvious choices within each category. It is thus critical that the central support function has clear policies and makes product choices in each technology area. At Glaxo, despite the lack of standards in end-user software, the IMD Director was adamant that only Intel chip based PCs would be permitted in the company, and this has parallels with UoG's non-support of devices not obtained through the University procurement system. In recent years, there has been a clear imposition of standards and product choices at the University as central IT strategy and policies have taken precedence over departmental initiatives.

Over the time duration between the two case studies, the Helpdesk function has evolved and adapted to changing requirements and developments in technology. The concept of support has also evolved, with Helpdesks or Service Desks increasingly seeing computer users as "customers", but at the same time end-users taking some responsibility for systems ownership, data maintenance and training. The super-user and data maintenance specialists have emerged as key link personnel between the computer user-community and central IT support.

RQ2. How has the Service Desk developed in response to the need for Cybersecurity?

Hila Meller, BT's vice president for Security, Europe, noted recently "security needs to be a concern across the whole organisation, not just the remit of the IT department. Everyone needs to play their part, to stop shadow IT and ensure data breaches don't happen" [21]. Nevertheless, the Service Desk has a key role to play in this endeavor, and Cybersecurity is now a major issue for Service Desk operations. Cybersecurity itself consists of "technologies, processes and measures that are designed to reduce the risk of a Cyber-attack (which is conducted through the deliberate exploitation of systems, networks and technologies)" [11]. This underlines the vast scope of Cybersecurity and points up the new capabilities, knowledge and skills required of the Service Desk personnel, who must play a key role in prevention, tracking and resolution of Cyber-attacks.

Digitalisation and the "disruptive technologies" pose new challenges. David Carvalho, Global CISO at OCS Group, has remarked that the Internet of Things (IoT) represents another area of emerging vulnerability. "IoT is everywhere, smart cameras, dumb cameras, all sorts of sensors, SCADA devices, and companies that use PLCs (programmable logic controllers). The whole world is producing IoT devices with few or no regulations at all" [22].

This is producing new demands on the training and reskilling of Service Desk staff. Mannie Romero, the executive director in the office of the CISO at Optiv, recently observed that "people who were network people in the past and are used to running discovery scans and doing things on the network and the system, now have to move up the stack to the applications and start learning APIs in AWS, Azure, and other cloud infrastructures. The situation is only going to get more challenging, as artificial intelligence, robotics, machine learning, and IoT become more prominent and widely deployed" [22].

In practice, this has seen Cybersecurity develop as a discipline or specialism in its own right in the business and consultancy fields, and as a major component of an organisation's operations, sometimes with a CISO reporting at Board level. For the Service Desk, as noted above, this has produced new and rapidly evolving demands on people skills and competencies. A recent report on Cybersecurity concludes, "Having the necessary technical personnel in place is one of the most important — and most difficult — elements of any organization's security posture. Organizations of all sizes and maturity levels struggle to attract and retain the right mix of people to help manage and secure their computing environments" [23].

In terms of technology deployment, Cybersecurity technology is becoming increasingly sophisticated. Threat prevention, for example, is a critically important component of a Cybersecurity strategy, and most organizations invest significantly in security controls and processes in this area. Oltsik notes, "Tools like endpoint security software, web threat gateways, and IPSs are designed to identify and block an assortment of activities deemed to be malicious". He adds, "Beyond blocking known malicious behavior, organizations must collect, process, and analyze internal and external data, identify and investigate suspicious activities, and remediate problems quickly before minor issues become major data breaches. The processes, tools, and personnel used for these tasks are generally referred to as security analytics and operations" [24]. Although there are some similarities in the business systems and desktop tools used by the two organisations in the two case studies spanning a thirty-year time gap, the technology requirements for addressing Cybersecurity issues are now on a different level. In the 1980s, the advent of the PC and the growth of end-user computing was the catalyst for the development of the Helpdesk with new skills requirements and supporting technology. In this decade, it has been the emergence of Cybersecurity issues that have driven a similar step change in Service Desk operations and staffing.

VII. Conclusion

The old Helpdesk is now increasingly seen as part of a broader Service Desk function, with service being defined as "an approach to IT service management that emphasizes the importance of coordination and control across the various functions, processes and systems necessary to manage the full lifecycle of IT services" [25]. This definition is often applied in the context of a third party service provider, but is also relevant to in-house IT service provision. At UoG, the Service Desk is the customer facing front end of all IT services, which are measured against stipulated service level targets defined in service level agreements. This aligns with the IT Infrastructure Library (ITIL) concept and definition of the IT Service Desk as the single point of contact between the IT function and users, which manages incidents and service requests, and handles communication with users. There is also a more subtle change in that the service is seen as supporting business processes and people capabilities along with the pure technology elements. The Service Desk now focuses on delivering high quality customer service to end-users, whereas the Helpdesk was more concerned with incident management and resolving problems related to IT in the organization.

The range of different technologies supported by the Service Desk has seen developments in its own support technology. In addition, the requirements set out in service level agreements have meant that Service Desks need to increase end-user satisfaction levels by responding to the incidents and problems within stipulated response times. To support this increase in customer service levels, support technology has become more sophisticated, involving elements of knowledge management and artificial intelligence.

Over and above this, however, as Peppard [26] has noted, the role of people skills and capabilities in delivering a successful Service Desk operation remains critical. In the context of Cybersecurity, this is true in its widest sense. As Bechkoum notes, "having an effective Cybersecurity culture within your organisation is vital" [27]. The key is to bring together relevant IT and security teams united through the actions of an empowered Service Desk. If the organisation is able to do this effectively, detecting the early warning signs of a potentially serious threat becomes easier. Such a preventative approach is likely to prove the most effective security model for most organisations. Despite advances in technology support systems, a fully automated Service Desk function remains some years away. Computing Research [2] have concluded "as the Internet of Things gathers pace, those data volumes will explode into something which we are all collectively struggling to even imagine. The role of AI and machine learning in security solutions in this sense is not a matter for debate. They simply have to play a role – and as data volumes grow, the role for AI will grow with it. However, for now and the foreseeable future, the role of AI in Cyber security is likely to remain as a partnership with humans. Neither can quite manage the task alone."

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Implementing the HERACLES Ontology

An Ontology as backbone for a Knowledge Base in the Cultural Heritage Protection Domain

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Abstract*—Environmental factors, worsened by the increasing climate change impact, represent significant threats to European Cultural Heritage (CH) assets. In Europe, the huge number and diversity of CH assets, together with the different climatological sub-regions aspects, as well as the different adaptation policies to climate change adopted (or to be adopted) by the different nations, generate a very complex scenario. This paper will present a multidisciplinary methodology that will bridge the gap between two different worlds: the CH stakeholders and the scientific/technological experts. Since protecting cultural heritage assets and increasing their resilience against effects caused by the climate change is a multidisciplinary task, experts from many domains need to work together to meet their conservation goals. In this paper we introduce the HERACLES Ontology, which structures data and explicitly links adjacent data. Furthermore the implementation of the HERACLES Ontology within the HERACLES Knowledge Base is described. Use cases and benefits of the application are given. The ontology comprises the following topics: Cultural Heritage Assets, Stakeholders and Roles, Climate and Weather Effects, Risk Management, Conservation Actions, Materials, Sensors, Models and Observations, Standard Operation Procedures/Workflows and Damages.

Keywords – HERACLES, Ontology; Knowledge Base; Ontology Visualization; Cultural Heritage; Ontology Population

I. Introduction

Cultural Heritage protection requires multidisciplinary teamwork – as discussed in our Paper at the SemaPro 2018 a common language is required. An ontology helps to explicitly express the knowledge of different domains. The presented ontology has been refined and brought to use in several modules, which we are going to introduce in this paper [1].

Europe has a significant cultural diversity together with exceptional historic architectures and artefact collections that attract millions of tourists every year. These incalculable values and global assets have to be preserved for future generations. Environmental factors, worsened by the increasing climate change impact, represent significant threats to CH assets such as monuments, historic structures and settlements, places of worship, cemeteries and archaeological sites. There are almost 400 UNESCO sites in Europe, located in different climatic European regions [2], [3]. Therefore, eco-compatible solutions and materials for the long-term sustainable maintenance and preservation of CH in response to the events induced by climate changes are a necessity. The research and development of these solutions will benefit from an Information and Communication platform able to provide a timely up-to-date situational awareness about the site, thus supporting decision makers to plan the actions necessary for long term and short-term maintenance, intervention and risk management against the threats of the climate change.

Section II, "Related Work" discusses Information and Communication Technologies (ICT) and existing ontologies and vocabularies in the CH domain.

Section III, "The HERACLES Project" introduces the project in which the ontology is developed and used.

Section IV presents the creation and content of the HERACLES ontology. It covers all relevant domains and expands the previous contribution by adding *Cultural Heritage Elements, Damages,* and *Reporting* to the Concepts.

In Section V, we present the HERACLES Knowledge Base (KB) and the HERACLES Mobile Application, in which the semantic application of the HERACLES ontology proves beneficial.

Finally, Section VI, "Conclusions and Future Work" recapitulates our findings and discusses directions for future developments.

II. Related Work

During the last 20 years, there has been an increasing interest and demand for specialized scientific technologies and methodologies in the CH field. An increasing number of experts from different scientific disciplines, such as curators, archaeologists, conservators, art historians, scientists and engineers, are involved in the analysis and study of CH assets and monuments, each one of them using his own specialized terminology. To overcome the communication gap among the CH experts, it is important to develop tools able to solve this issue. Information and Communication Technologies can support this interdisciplinary research [4].

Firstly, electronic handbooks, web-based knowledge platforms together with mobile phone applications, expert and decision support systems have been developed to improve the handling of the data and to promote the dissemination and a better understanding of the scientific information from the technical investigations. Above all, these ICTs facilitate the cooperation between CH experts. Two examples of Web knowledge tools, platforms and applications, developed by CH organizations and museums, are the following:

- An interactive website by the TATE Gallery presents information about the artworks identity, the materials, the structure and the construction technology, the description of the conservation steps, the investigation procedures, the results and the assessment of their condition state [5].
- Diadrasis, a nonprofit organization, has developed an online application entitled Viaduct [6], which classifies and explains a number of analysis and dating methods and provides basic information about the investigation methods and the related glossary.

In parallel, a correct and controlled terminology has become particularly important in the electronic documentation and presentation of the assets and of their restoration. In this respect, a number of thesauri, terminology glossaries, vocabularies and databases have been introduced, for example:

- The Art & Architecture Thesaurus (AAT) is a structured vocabulary used to improve the understanding of the terms about art, architecture, and material culture [7].
- The European illustrated glossary of conservation terms for wall paintings and architectural surfaces (EwaGlos) is an illustrated glossary of conservation terms translated in eleven languages. The core of the glossary includes approximately 200 definitions of the terms frequently used in the field of the conservation/restoration of the wall paintings and of the architectural surfaces [8].
- NARCISSE, a European project, has developed a very high-resolution image bank, dedicated to the art treasures of Europe major museums. A multilingual glossary of terms about the conservation of paintings, illustrated with various spectral images, was developed [9].
- POLYGNOSIS is a web-based knowledge platform, designed and implemented with an educational orientation, concerning the optical and laser-based investigation methods for the study of CH objects [10]. POLYGNOSIS handles information related to the analysis of the studied materials and in this respect it offers an important background for the HERACLES ontology regarding the characterization of materials.

The design process of the HERACLES ontology included the research and analysis of existing ontologies.

During this, the ontology developed by The International Committee for Documentation, an institution of the International Council of Museums, CIDOC Conceptual Reference Model (CIDOC CRM) was analyzed. CIDOC CRM is an ontology intended to facilitate the integration of heterogeneous cultural heritage information [11]. It is designed since 1996 and has been continuously refined since. It offers for cultural heritage and information of interest a general data structure, whereas the general purpose are museum documentations and exhibition objects shown in museums. CIDOC CRM is supra-institutional and can be applied independent of any local context. The ontology is very progressive at structuring information about the origins of an asset, e.g., the creation of an artefact or its chronological classification. Yet, the ontology was too complex and heavy-weight for the HERACLES project; furthermore, it focused mainly on cultural heritage as object in an element in an exhibition. Nevertheless, CIDOC CRM can be extended with additional models, such as the CRM scientific observation model, or the CRM model for archeological buildings.

Acierno et al. introduce in [9] ontological work based on CIDOC CRM. The ontology presented ontology expands the previously named model by adding buildings and elements of buildings through a fine-grained model, which contains horizontal and vertical components. Further, it adds workflows aiming at the conservation of cultural assets. Based on this ontology, a connection between a Building

Information Modelling Software and the classes describing buildings was established, which yielded into a knowledge enriched 3D model of the researched artefacts. Both building design and knowledge-enriched visualisation are high-grade outcome and deserve further examination.

Zhang et al. introduce an ontology based framework for a KB about materials and their compatibilities [13]. This domain is important to the HERACLES Project, since conservators and restaurateurs often have to find appropriate materials with custom properties, on order to repair and protect cultural heritage and not worsen its preservation state and aesthetics. The focus of this work lies within choosing materials for manufacturing processes and omits sensitivities or compatibilities of material combinations. Since the compatibility of conservation materials used in cultural heritage preservation is an important aspect, Zhang's ontology does not meet our requirements.

In the MONDIS project, Cacciotti et al. developed the Monument Damage Ontology [14]. It is suitable for both conventional documentation of cultural heritage, as well as describing damages occurring on cultural heritage. The proposed modelling enables the ontology to distinguish between the consequences of an effect (e.g., crack or flaking*)* and the mechanisms that led to it (e.g., temperature changes or acid rain). The description of damages and their occurrence seems to be well suited for describing damages on CH. Also, the authors give suggestions on how to handle damages, which are mainly based on historical data. Here, the semantics have to be analysed by the reader: no explicit semantics for conservation methods are introduced in the ontology.

However, no holistic approach had been undertaken, modelling all required domains in an application oriented project. Fearing that including new concepts into existing ontologies would lead to complexity, it was decided to not supplement existing ontologies, but to create a new ontological model from scratch trying to keep it as concise as possible. The ontology was developed in a workshop with stakeholders of the project with in-depth domain knowledge background, as described by Moßgraber et al. [15]. Hereby, it incorporates all domains that are relevant for the end-users.

The following sources have been used as reference material for the new ontology: the SWEET ontologies developed at the NASA Jet Propulsion Laboratory [16], the materials ontology from Ashino [17] and Open Geospatial Consortium (OGC) standards such as the SensorThings Application Programming Interface (API) [18] and the Internet of Things (IoT) Tasking Capability [19].

III. The HERACLES Project

The main objective of the HERACLES project was to design, validate and promote responsive systems and solutions for effective resilience of CH against climate change effects, considering as mandatory premise a holistic, multidisciplinary approach through the involvement of different expertise (end-users, industry, scientists, conservators, restorators and social experts, decision, and policy makers) [20].

This was pursued with the development of a system exploiting an ICT platform able to collect and integrate multisource information. With the help of this platform, complete and updated awareness was provided. It facilitated the integration of innovative measurements improving CH resilience, including new solutions for maintenance and conservation [21].

The validation has taken place on four test sites, namely Heraklion in Crete with the Minoan Palace of Knossos and the Venetian Sea Fortress of Koules and Gubbio in Italy with Consoli Palace and the town walls. These test beds represent key study cases for the climate change impact on European CH assets.

The strength of HERACLES solutions is their flexibility in evaluating a large quantity of different pieces of information utilized via explicit semantic modelling tailored to the specific CH assets needs. In this context, end-users play a fundamental role. Through consequent end-user focus, we aim to develop a complete, yet flexible system that is able to embrace other test-beds as well. End-users have an active part in the project activities and have permanent access to the HERACLES KB, which implements the HERACLES ontology presented in this paper. Through the ontology, the stored and retrieved knowledge from the KB is language independent.

The HERACLES project endured from May 2017 until April 2019. The webpages are still available and will deliver information until 2021 [20].

IV. Design of the HERACLES Ontology

As outlined in the section "Related Work" we decided to create a new concise ontology model. To identify the ontological classes and relations, a workshop was held, which brought together all stakeholders of the project with their different research and domain knowledge backgrounds. This group consisted of about 20 persons. For a workshop, this number is considered too large, but was necessary due to the different required domains.

The following graphical conventions are used for the description of the HERACLES ontology:

- Green boxes represent concepts; grey boxes represent instances.
- Continuous arrows represent semantic relationships between concepts or instances. Inverse relationships are omitted for better readability. A label next to an arrow describes the relationship.
- Dashed arrows link subclasses to parent classes.
- Dotted arrows link instances to their concepts.

Concepts in the ontology are accompanied by attributes (datatype properties). For example, an asset can have geographical coordinates or a construction period. For the sake of brevity, these are omitted in the ontology pictures.

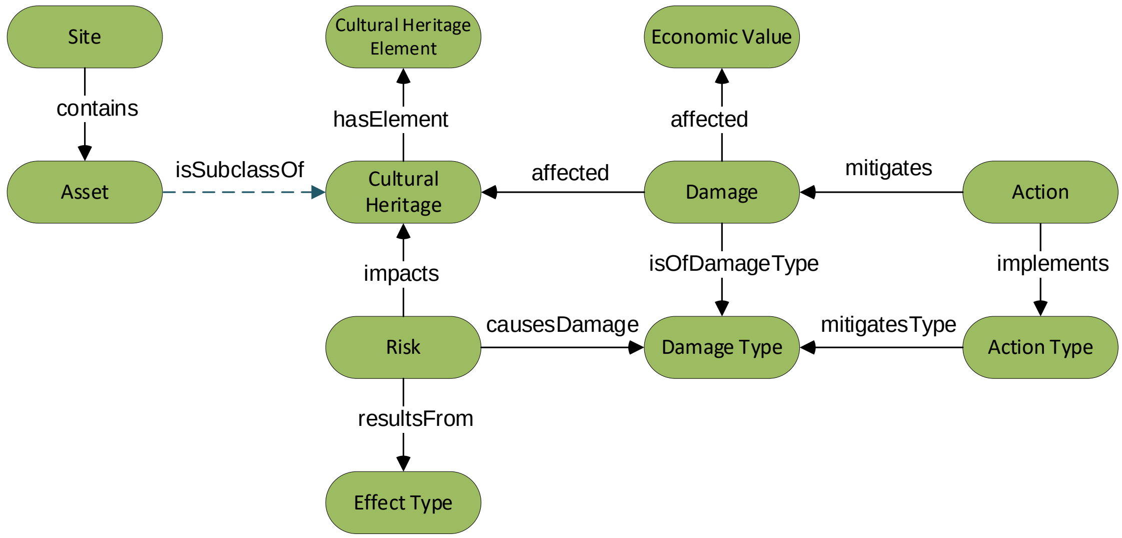

Figure 1. The main concepts and their object properties of the HERACLES ontology.

The central elements in the ontology are the CH assets that need to be protected against the effects of climate change. As shown in Figure 1, a top-level class is defined to refer to any kind of CH. Risks arise from climate change effects which can cause damages to CH.

A. *Cultural Heritage Assets*

Assets, which are the focus of the project, are a subclass of CH. The Asset concept is further refined with the concept Structure and, below that, Monument, Building or Wall (see Figure 2). Via these classes, the actual instances of the test beds of the HERACLES project, like the “Knossos Palace”, the “Palazzo dei Consoli”, the “Venetian Fortification” and the “Gubbio Town wall”, can be included.

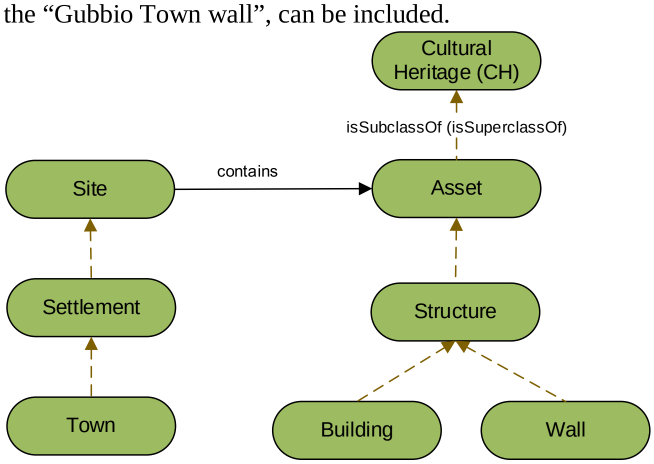

Figure 2. Cultural Heritage Asset

B. *Cultural Heritage Element*

In the run of the HERACLES Project, it became clear that a Cultural Heritage often grows naturally in the run of time and has different trait, characteristics, materials and so forth. To take this into account, the class *Cultural Heritage Element* was introduced (Figure 3). It describes parts or subparts of a *Cultural Heritage*, whereas a *Cultural Heritage Element* can also contain another *Cultural Heritage Element*. An example would be the Venetian Fortress in Heraklion, which consists of different floors, which again have different rooms.

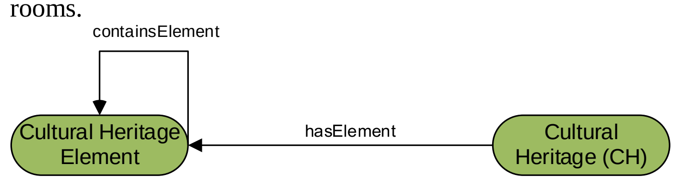

Figure 3. A Cultural Heritage is made up from several Cultural Heritage Elements, which can again contain other Cultural Heritage Elements.

C. *Climate Change Effects*

In Figure 4, the distinction between potential, meaning things that may occur and facts, in the sense of actual occurrences, is emphasized. This distinction applies to effects and damage. As an example, the ontology may contain flood as a potential effect type that may damage an asset. Besides that, the flood episodes that occurred in specific years are also registered as actual occurrences in the KB. The ontology contains the relationships between potential effects (“Effect Type”), follow-up potential effects (“leadsToEffect”) and the potential damage (“Damage Type”) they may cause. An example with instances for the classes shown in Figure 4 is given in Figure 5. The parameter *Heavy Precipitation* can lead to *Landslide*. If such a Landslide hits an asset, it can result in *Structural Damage*. A specific event is shown below these generic types: A heavy precipitation episode occurred at a specific date and time, which caused a landslide in a specific area, which hits a wall and destroys it.

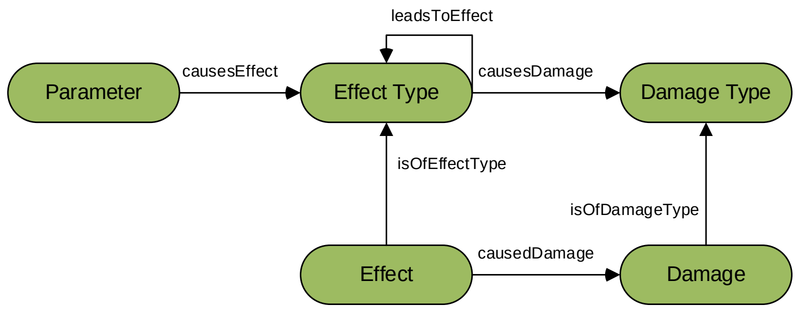

Figure 4. Distinguishing Effect and Damage, Effect Type and Damage Type

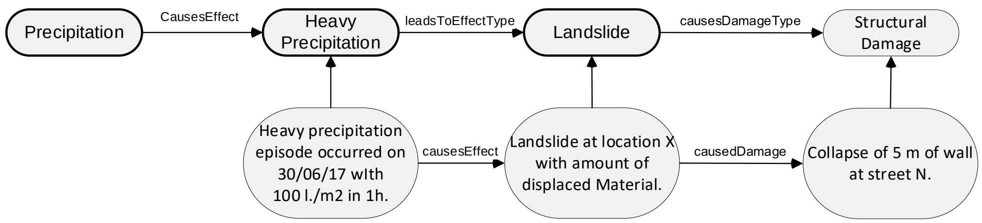

Figure 5. Example for effects and caused damage and their types.

D. *Sensors and Simulation models*

To capture climate change relevant parameters, sensors were modelled according to the SensorThings API standard, which was presented by the OGC. The SensorThings API is a modern standard for providing an open and unified way to connect IoT devices, data and applications over the Web [18]. Therefore, the initial design of the ontology classes for dealing with sensor metadata is based on the data model of the SensorThings API standard. It is reasonable to follow the same standard for developing the ontology for simulation models. In practice, requesting the execution of a model is equivalent to tasking an actuator to perform a particular task but, since the tasking part of SensorThings API was not yet available, it is not considered in the paper. For this reason, the adaptation of the ontology is based on the "Internet of Things Tasking Capability" [16], in which an extension of the SensorThings API for tasking actuators is proposed. The central concept in the diagram (see Figure 6) is the "Asset Representation".

An Asset Representation is an entity that provides data about an asset. It can be regarded as a proxy that enables access to the available data about an asset, for example, temperatures in a building, images and measurements of the building obtained in a measurement campaign or the results from a structural model. The actual sensor measurement is stored in an observation, which is connected to a data stream. The four classes on the left in Figure 7: TaskingCapability, Task, InputParameter and ParameterValue, provide support to store and manage metadata about the models. The TaskingCapability provides a human-readable description of the model together with information regarding the API that the model provides. In the HERACLES platform, there is an additional abstraction layer, namely the KB, which manages the metadata of the available models and sensors.

E. *Maintenance and Response Actions*

Situational awareness is achieved through continuous monitoring of the status of the CH assets combined with the results provided by the simulation models, which enable risk assessment. Evaluation of the information provided by the system and on-the-field observations enable the identification of actual or potential problems, for instance, when a risk level threshold is trespassed or a damage is observed. The modeling of such problems has been included in the ontology. Maintenance actions not related to an issue also need to be documented. In this way, the structure of the ontology can serve as a register of past actions that can be used to better understand the current situation and support the decision making process. Suggested actions are documented in formalized guidelines, which are often supported by a specific law; these are the Standard Operating Procedures (SOPs) (see Figure 7).

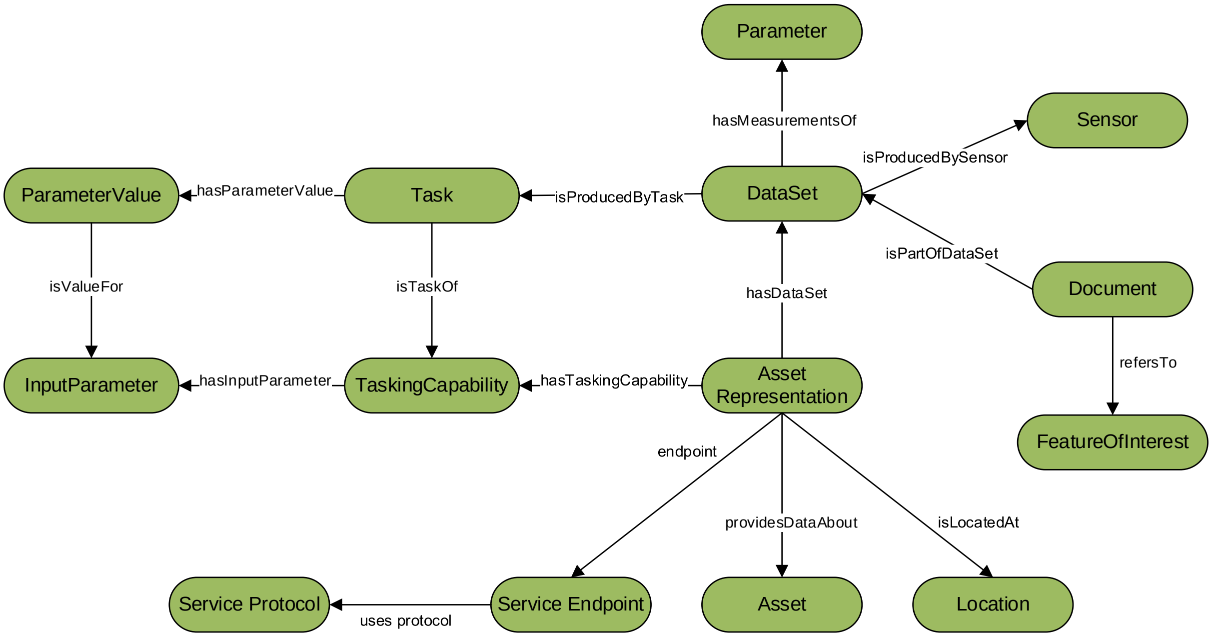

Figure 6. Classes for managing metadata of sensors, models and measurement campaigns.

F. *Materials*

Since materials have an influence on how an asset is affected by climate effects in terms of its resilience to weathering and ageing, it is important that the ontology also models information about materials and the KB contains information about materials and of which materials an asset consists of. The material area can be ground for experimentation of new solutions to be applied for maintenance and restoration/conservation of CH assets. The classes to keep materials information in the KB are provided in Figure 8.

The level of detail regarding the information about the composition, structure and properties of the materials needs further discussion with both materials experts and end users.

Nevertheless, it should be noted that some ontologies associated with the handling of material related information already exist [10]. Whereas the detail of such specialized ontologies may be too excessive for its application in our use cases, they provide a reference to develop a model for the HERACLES platform. At the same time, since the aforementioned ontologies are not designed with a specific application field in mind, extra classes and properties may be necessary in the HERACLES platform for its utilization in the context of CH conservation.

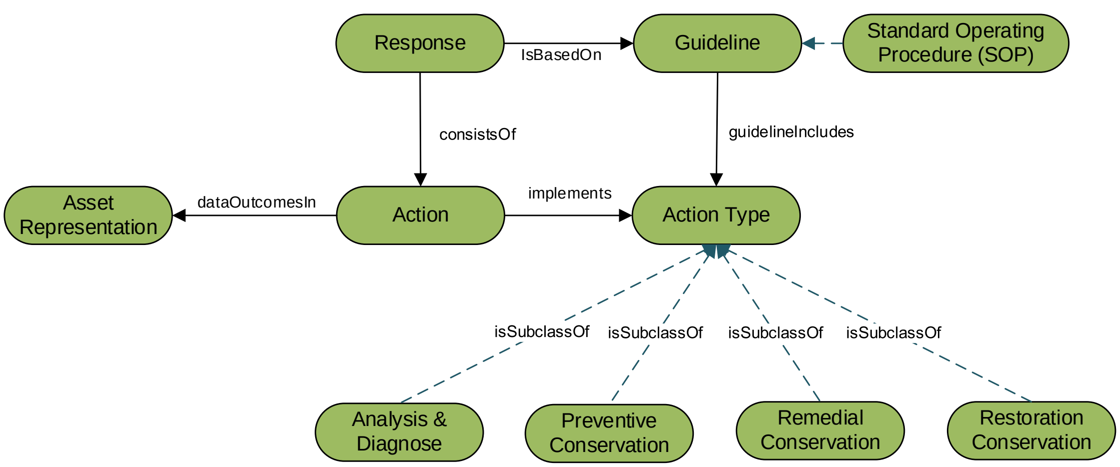

Figure 7. Maintenance and response actions

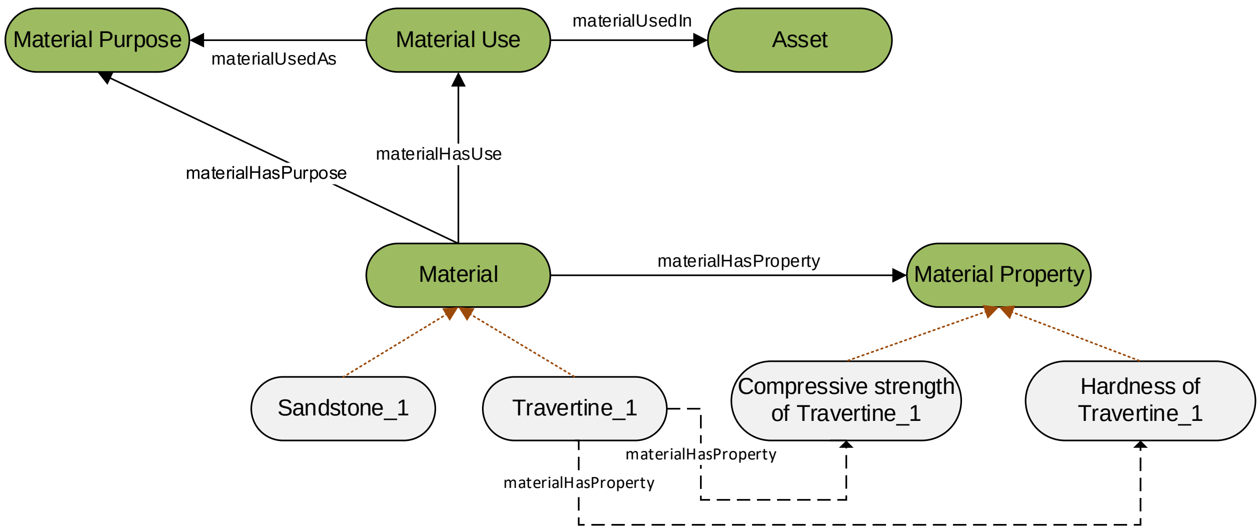

Figure 8. Classes keeping material information

G. Damages

An important aspect is modelling damages in this project (Figure 9). A *Damage* affects a *Cultural Heritage*, which is caused by a specific *Effect*, such as a wet-dry cycle or rapid temperature changes (see Figure 4). The twofold approach allows categorizing *Damages* into *Damage Types*. *Damage* is the actual manifestation of the occurring damage. Through the generic categorizations, it is possible to give suggestions for specific *Action Types* that proved successful in the past on the same *Damage Type.*

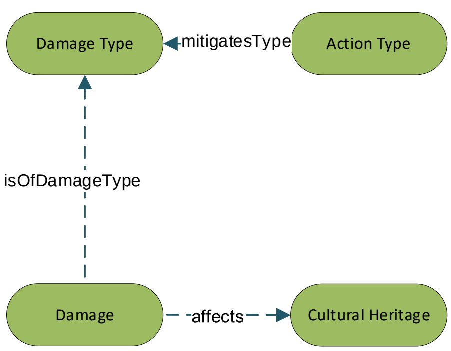

Figure 9. Classes for damages and its causes

H. Reporting

The classes required for reporting are depicted in Figure 10. A *Report* reports for a *Cultural Heritage*. It has a relation to a specific *Damage Type*, where the type of the reported *Damage* is specified. Section V describes the usage of this part of the ontology by means of the HERACLES Mobile Application.

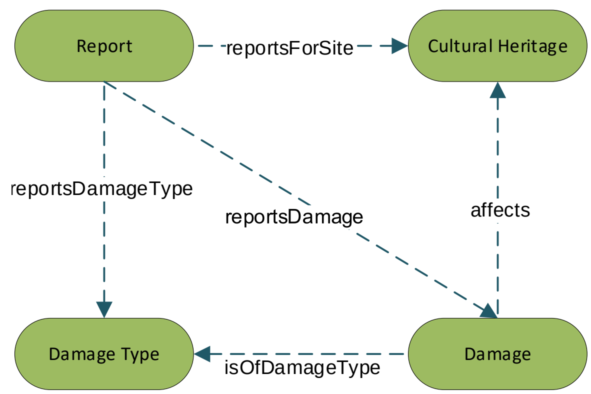

Figure 10. Classes describing the domain Reporting

I. Ontology Metrics

This section provides the metrics of the current state of the HERACLES ontology. It includes *general* metrics like the number of classes, data/objects properties and individuals and *annotation axioms* like the numbers of annotation property. Inverse properties are excluded in this listing (see TABLE I).

TABLE I. ONTOLOGY METRICS

Metric	**Value**
Class count	109
Object property count	102
Data properties count	49
Individual count	141

V. Applying the HERACLES Ontology

This section extends the original paper from the SemaPro 2018. Uses cases, directly related to the HERACLES Ontology are described below. The first Section V.A introduces the semantic integration of data according to the HERACLES ontology. The subsequent Section V.B shows scenarios, in which data is retrieved from the ontology.

A. *Structuring Data through the HERACLES Ontology*

The HERACLES KB offers input forms, through which data can be semantically integrated (Figure 11). If, for example, the creation of a new Asset is required, the input form offers text fields for textual descriptions. Links to other instances (as allowed by the ontology) can be created through selecting the appropriate elements in lists. This is a simple creation possibility for non-technical users. The picture below shows the creation of an example instance. It contains a unique name, as well as a display name. Representations of this instance are shown in the *Has representation* list.

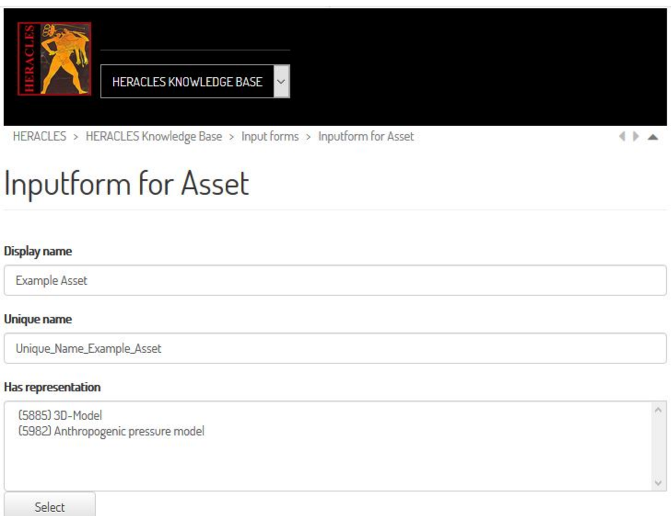

Figure 11. The manual creation of an instance and its relationships

Besides the manual possibility, an online endpoint was established. By sending messages per HTTP in the appropriate structure to this endpoint, instances in the ontology can be created or deleted. The structure must adhere to the HERACLES Ontology; otherwise, it is not accepted. By using the built-in authentication mechanisms of the KB component, the access to these commands can be restricted to certain users depending on their associated roles. A new Cultural Heritage instance for example, could be reported through the message shown in Figure 12. The key *defaultprefix* contains the value of the namespace of the HERACLES Ontology. The element *newInstance* is created as instance of *CulturalHeritage*. The KB assigns the new instance the unique name *newHeritage* and display name *newHeritage*. The key *text* contains a free description of *newHeritage*.


```
{
"defaultprefix" : "http://iosb.fraunhofer.de/heracles-kb/",
    "data": {
        "newInstance" : {
            "type" : "CulturalHeritage",
            "properties" : {
            "instanceDisplayName" : "newHeritage",
            "instanceUniqueName" : "newHeritage",
            "text" : "Description"
            }
        }
    }
}
```


Figure 12. Using the online endpoint for machine to machine communication

B. *Applying the HERACLES Ontology*

The ontology serves as the backbone of the HERACLES KB. Every entry in the KB is also an instance stored according to the ontology. Therefore, all relationships to other instances are directly available.

In Figure 16, an excerpt from an entry of the KB is shown. The page contains a customized view, showing pictures and quick links to the most important relations. On the right side, all relationships are shown. These are, for example, damages impacting this heritage, reports about this heritage or sensors monitoring this heritage.

If the user wishes, s/he can create ontology pictures, which give quick access to the most important or used related instances. Figure 13 shows the report *testReport*, which reports a damage of type *salt accumulation*. A click on the boxes will lead the user to the respective entry, where a view as shown in Figure 15 will give all available information and related data.

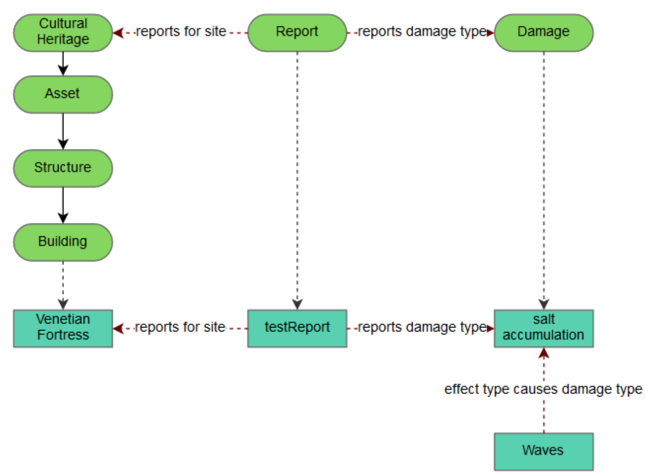

Figure 13. An ontology picture customized for the Venetian Fortress showing a report reporting about a salt accumulation

Depending on the user's authorization status, s/he can manipulate the pictures by dragging and dropping or through right clicking, as shown below in Figure 14.

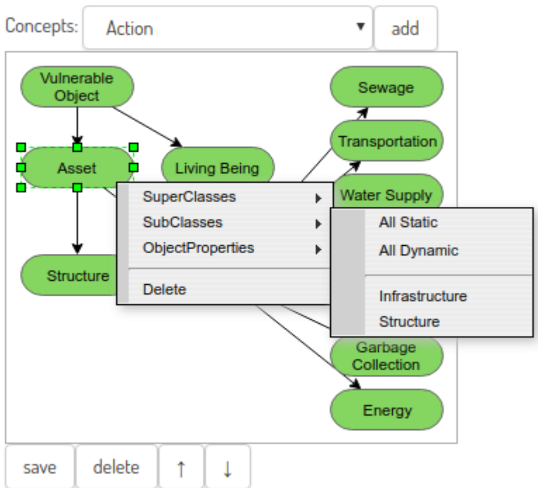

Figure 14. Tool with graphical ontology visualisation

The endpoint mentioned in Section V.A is, amongst other technology, used by the HERACLES Mobile Application. This app allows the user to report damages on site from the surveilled cultural heritage. The location, including the description by the researcher on site, as well as additional pictures, videos or speech messages are transferred to the knowledge base where they are presented to the cultural heritage manager. Through the semantic structure, not only the report, but also the heritage it belongs to, as well as the reported damages are presented.

The picture below shows a *testReport* that has been sent through the HERACLES Mobile Application. It contains the damage type, the heritage it is reported for and a picture of the reported damage.

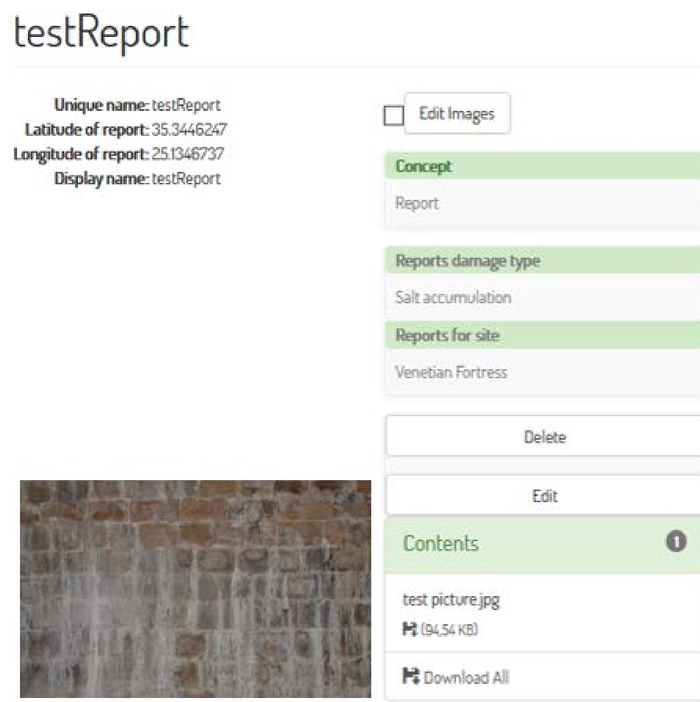

Figure 15. The instance page for a hypothetical *testReport*

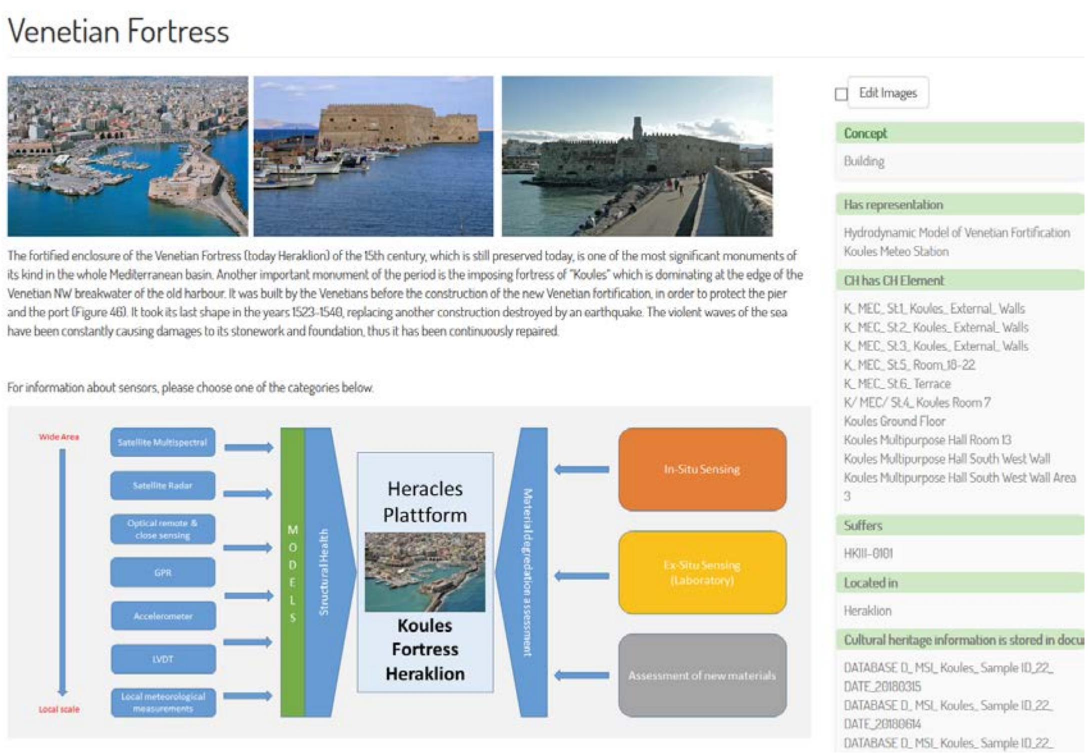

Figure 16. An instance page for a cultural heritage showing all related data

Figure 17. Using metadata for map views

Metadata, such as the location is used to visualize the position of reports on a map (Figure 17). A click on the icon will lead the user to the entry of *testReport*, as shown in Figure 15.

VI. Conclusions and Future Work

This paper presented the design of the HERACLES ontology, which aggregates multiple domains and therefore, required the interaction of multiple domain experts. Furthermore, it gave an introduction to the usage possibilities of an ontology. Bringing it all together in a Knowledge Base gives both a commonly agreed on vocabulary, as well as a browsable data structure, in which collaborators can access all related data. This brings up connections and makes correlations understandable. Though the HERACLES Project ended in April 2019, the ontology can be the basis for further research projects, which need to tackle the problems of climate change effects and involve data from heterogeneous domains. As written in III, the HERACLES Platform, and therefore the HERACLES Ontology, have been validated at hand of four different use-cases, in which the ontology comprised and linked all collected data [20].

Apart from future possibilities, the ontology is implemented in the HERACLES KB, in which project end-users continue working. The ontology is set from now and will serve as structure for future data, which is going to be integrated into the KB.

Future projects could focus on reasoning about, or integrating rules into the ontology, to make use of its full potential. Action should also be taken on mapping concepts from the HERACLES ontology to other prominent models, like the CIDOC-RM, to guarantee interoperability and facilitate the ontology's reuse.

The ontology has been published here [22], where the interested reader is encouraged to examine it.

Acknowledgment

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Exploring Various Aspects of a Video Learning Channel: The Educational Case Study of Eclips

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***Abstract*—In recent years, video tutorials have become an important tool to enhance active student learning. They are considered to be an effective and efficient instrument to enhance the progression of students. In 2016, the Faculty of Business and Economics of the University of Antwerp developed a strategy on technology-enhanced learning, with a strong focus on the creation and the use of both course specific and integrative video tutorials. To make the tutorials available to students throughout their entire study career, the faculty started in 2017 with the development of a faculty-wide learning channel, called Eclips. The platform offers students the opportunity to prepare for a lecture, revise learning content and fill knowledge gaps across the curriculum. In this paper, the structure, design, and content of the learning channel are elaborated. As adoption is crucial for any new technology, various statistics about the content and usage during the first two academic years are presented. Finally, as e-learning technologes are often considered to be disruptive, some possible new value networks are explored, including other target groups and interactions with the broader societal environment.**

Keywords–Technology Enhanced Learning; Blended learning; Digital learning channels, Disruption in learning.

I. Introduction

This paper extends a previous paper which was originally presented at the Eleventh International Conference on Mobile, Hybrid, and On-line Learning 2019 [1].

The importance of *e-learning* and *Technology Enhanced Learning (TEL)* has grown in recent years. Several scholars consider this as a crucial, and potentially even disruptive force in higher education [2]. While there is an ever growing supply of online e-learning tools and *Massive Open Online Courses (MOOC)*, universities are also encouraged, and even forced, to develop their own initiatives to supprt Technology Enhanced Learning. For instance, accreditation bodies like the *European Foundation for Management Development (EFMD)*, strongly advise universities to increase the use of TEL [3].

The University of Antwerp, in particular the faculties *Faculty of Business Economics (FBE)* and *Faculty of Medicine and Health Sciences (FMHS)*, has been focusing for several years on the use of video tutorials to address the heterogeneous incoming students, and to improve the long-term knowledge of students across the curriculum. The existing video tutorials were selected by the lecturers to make sure that the quality and the level were aligned with the final objectives of the programmes. These videos were used during the course or served to clarify certain topics of the course. Lecturers could also create their own videos in the recording rooms that have been available on the different campuses of the university.

However, there was no platform available to collect, group, and structure all this information. Therefore, the *Faculty of Business Economics* decided in 2017 to create a comprehensive digital learning channel in order to create a clear and structured collection of content for both students and lecturers. This offering should enable the students to navigate in an easy way through all the content that they have learned during their bachelor and master years. By creating this integrated video platform, called the *Eclips Learning Channel*, the faculty wants to give the students the possibility to revise the subjects at their own pace and to consult educational video material (also used in previous study years) when they feel it is necessary to do so. It also gives lecturers a complete view on the study material that students are supposed to have absorbed.

In this paper, we use a case-based approach, based on the *Eclips Learning Channel*, to explore several key aspects of the design, organization, and adoption of such a faculty digital learning channel. In Section II, we give a brief literature overview of the possible power of video as a teaching medium, discuss some aspects related to the adoption of technologies, and present the overall strategy of the faculty to leverage this technology. In section III, we refer to the literature related to the disruptive nature of e-learning technologies, and explore some possible implications for the learning channel. The actual structure, content, and design of the *Eclips Learning Channel* are detailed in Section IV. Section V is concerned with adoption, and gives an overview of the main realizations in terms of content development and student usage, distinguishing between an initial phase and a second phase. In Section VI, we explore some possible new value networks, discussing the current and future efforts to broaden the scope and reach of the video learning channel. Finally, we present some conclusions and limitations in Section VII.

II. Academic Video Tutorials

A. The Case for Video Tutorials

Apart from the great advantage of flexibility, video can be a very powerful teaching medium, as stated by Thomson et al.[4]. Video tutorials, often presented as screencasts, are short videos adopted by lecturers to stimulate active learning during the course. In the form of shorter mini-lectures, such as explanations of assignments or exam solutions, they can be used as supplementary resources when teaching a module

[5]. Research, for instance by Morris and Chikwa [6], has confirmed that students prefer short screencasts that summarise lectures, or delve in-depth into complex concepts. Lloyd and Robertson demonstrated positive learning gains in an undergraduate statistics course for students using a supplemental video tutorial [7].

Apart from being part of the lecturer's own module, video tutorials can also be used to cope with the heterogeneity of student groups by offering students the opportunity to refresh knowledge or to fill up knowledge gaps. Research by Pinder-Grover et al. showed that screencasts lead to demonstrable improvements in course performance, especially for those students who enter with the least amount of exposure to the subject matter [8]. These hiatus frequently occur at the beginning of a study career, because of lack of background in a certain topic or limited prior knowledge when entering university. Moreover, it is also manifest that students continuously need to refresh specific topics during their study career, because of the inevitable process of knowledge evaporation.

B. Adoption of TEL and E-Learning

The adoption of an innovative technology is not a trivial thing, and has been extensively studied. In his seminal work *Diffusion of Innovations (DOI)* [9], Rogers described the lifecycle of innovations in terms of their adoption. In 1989, Davis proposed his *Technology Acceptance Model (TAM)* [10], stating that the individual adoption of a technology is primarily based on it's perceived usefulness en it's perceived ease of use. This model, which has been refined throughout the years [11], is considered to be an important reference model for the adoption of new technologies.

As e-learning technologies are innovative technologies that require a change in the behavior of both students and lecturers, the adoption of e-learning technologies in general and a faculty learning channel in particular is crucial. Therefore, in accordance with the *Technology Acceptance Model* [10], the perceived usefulness and the perceived ease of use were considered to be prime directives during the design and implementation of the *Eclips Learning Channel*.

C. Faculty Strategy on Video Learning

At the Faculty of Business and Economics of the University of Antwerp, video tutorials tended to be part of a certain course module, confined to the related course within the *Blackboard Learning Management System (LMS)*. In order to make video tutorials available for students during their entire study career, the faculty decided to set up a digital learning channel with permanent and mobile access. In this way, students can watch the tutorials during their studies whenever they need to, and lecturers can refer to this channel in a cross-curriculum way.

The faculty has organised its courses based on domains or so-called *Learning Tracks*, and leverages this structure to deal with various aspects or cross-cutting concerns of academic courses, such as internationalisation and examination formats [12]. Therefore, it was decided to organize the *Eclips Learning Channel* based on these same learning tracks: Business Economics, Economics, Quantitative Methods, Engineering, Information Systems, Business Communication, Research Methods and Broadening Subjects. The faculty also decided to adopt an hybrid model for its video tutorials, using both in-house produced tutorials and existing clips from external providers. When the channel was first implemented and launched at the start of the academic year 2017-2018, it was primarily targeted at first-year undergraduate students, i.e., the first bachelor year. The main emphasis was on providing video resources for this group of students. In the academic year 2018-2019, the focus moved towards the second bachelor year, in order to keep serving the original target group of students.

In order to support and encourage the in-house creation of video tutorials, the faculty set up a dedicated ECLIPS recording studio. When developing a video tutorial, different video production styles are offered to lecturers by the production team. Production styles include screencasts and recording with a glassboard or green screen. It is important to provide a variety in video production styles, as standardisation of video production faces many limitations, as stated for instance by Hansch et al.: *It is important to match the video style to the instructor. There is not a one-size-fits-all approach* [13]. For the sourcing of the video tutorials from elsewhere, the faculty relies upon their faculty staff to assess the quality and consistency of the selected video tutorials. In order to support the quality control and assessment, a quality checklist and a list of guidelines were developed to support the evaluation of both in-house made and external video clips.

III. E-LEARNING AND DISRUPTION

The terms *disruptive technologies* and *disruptive innovation* were first defined and analyzed by Clayton Christensen [14]. It refers to an innovation that creates a new market and value network and eventually disrupts an existing market and value network, as opposed to *sustaining innovations* or developments that maintain existing value chains and incumbents. Christensen himself has argued that e-learning technologies are fundamentally disruptive [2][15], and will probably disrupt the educational landscape and value networks.

Though the notion of disruption features heavily at conferences on e-learning and learning technologies, industry experts like Peter Philips wonder whether we are really ready to embrace disruptive e-learning technologies, and ask who is going to drive the disruption [16]. And indeed, we can clearly see inertia in the application of e-learning technologies, as for instance *Learning Management Systems (LMS)* are still mainly used to publish *PDF files*, and lectures are often recorded from beginning to the end, year after year. Nevertheless, indications exist that education value chains may be overturned in the future by e-learning technologies. Consider for instance that students are already turning to online resources such as *Khan Academy* for assistance, or requesting to replace introductory courses by an online *MOOC* of a world leading university.

Therefore, academic faculties and institutions should actively look to participate in, and/or to establish new value networks in education. In order to gain knowledge of applying e-learning technologies and to participate in collaboration efforts, the faculty decided in the academic year 2016-2017 to participate in the collaborative development of an online course on *Research and Writing Skills for Projects and Dissertations* produced by *Epigeum* [17]. To emphasize the architecture of collaboration, this online course has been integrated in the *Eclips Learning Channel*. Moreover, it was decided to explore new partnerships and opportunities for new value networks during the development lifecycle of *Eclips*.

IV. Design and Realization

In this section, we detail the actual development of the *Eclips* learning channel, including three main aspects: structure, content and design. But in accordance with our emphasis on the adoption of this innovative technology [10], we first discuss the approach to create an overall concept for the learning channel, and to gather people around it.

A. Approach

As a first step, lecturers who showed interest in *Digital and Blended Learning and Teaching (DBLT)* before, were contacted and asked for input regarding the content of the learning channel. In order to ensure that the entire faculty was represented, these lecturers were selected across the various departments. Moreover, the content of the learning channel was discussed on the department meetings of these departments. All this information was collected in order to get a good overview on the information that lecturers believed to be necessary for their own course. Since the students are the main target group, a workshop was organized in which a group of 21 students were asked to give their opinion on the structure, content and design of the learning channel. This feedback was taken into account during the further development of *Eclips*.

As with other pedagogical aspects or so-called *cross-cutting concerns*, such as internationalisation and examination formats, the structure is based on the eight learning tracks within the faculty [12]. The project was initially defined for a three year period, during which the faculty envisioned to add content in a gradual way. In accordance with considerations for adoption [10], significant attention was given to the visual or graphical aspect of Eclips during the creation of the learning channel. In order to make the adoption of the learning channel successful, the two target groups — students and lecturers — needed to be reached, informed and actively stimulated. As stated before, the focus during the first academic year was on the courses of the first year bachelor. Therefore, the main target group initially consisted of the first year's students who were informed in the information sessions at the beginning of the academic year. In their welcome package, they received for instance a pen with the Eclips logo. For the adoption by other students (Bachelor 2, Bachelor 3, Masters) the faculty was counting on the second target group to spread the word. This second group, the lecturers, was informed during the yearly staff meeting in the beginning of the academic year. They were also invited to take a look at the recording room containing the necessary supporting equipment to record video tutorials.

B. Structure

The learning channel is embedded in the Blackboard Learning Management System (LMS), and has a clear structure to navigate, both for students and lecturers. The *Eclips Learning Channel* presents video tutorials and digital modules according to the structure of the eight learning tracks within the curricula of the various study programs of the faculty. For every learning track, the responsible lecturers decide and define their own substructure by mutual agreement within the learning track. Mindmaps are used to guide the students and lecturers throughout the entire structure.

The technology realizing the internal structure of the channel is quite elementary and consists of two basic building blocks: the electronic learning platform Blackboard and a PowerPoint presentation to represent the mindmap structure, which is converted into an HTML5-package within Blackboard. The *Eclips Learning Channel* is made available as a separate course in the list of courses within Blackboard, and is accessible to all students and lecturers of the faculty. Opposed to other courses, the learning channel will be visible during the entire academic lifespan of both the student and lecturer. When the student or lecturer clicks on Eclips in Blackboard, he is presented with the main HTML5-mindmap, as represented in Figure 1.

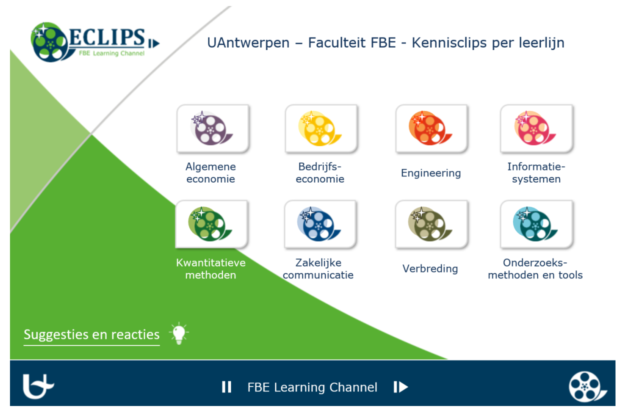

Figure 1. Main structure of the mindmap.

When navigating to a video tutorial in the mindmap, an information sheet shows details about the author, the production date and duration of the video, the hosting platform or source, and a short description of the video content. Each information sheet has a unique identifier that refers to the video tutorial or digital module. The video can be started by clicking on the play button in the right corner of this information sheet, as represented in Figure 2. The use of hyperlinks behind

Figure 2. Example information sheet of a video tutorial.

the icons in the mindmap ensures that the user can navigate through the different learning tracks to find the video tutorial or digital module that he or she wants to consult. The technology used to create the HTML5-package ensures that users are able to navigate through the mindmaps and watch the videos on their mobile devices. This concern was expressed during a workshop organized with the students, and is closely related to the perceived usefulness [10].

In case a student has a suggestion to upload a video tutorial in the learning channel, or there is an error in the video tutorial, the student can contact the *Eclips team* through an interactive forum. Using the unique identifier in the information sheet, the student can easily refer to a specific video tutorial.

C. Content

As mentioned before, in the first academic year of the project (2017-2018), the faculty focused on courses for the first year bachelor students. More specifically, the focus was on the courses with a low pass rate and/or the courses taken by a high number of students, i.e., Accountancy, Economics, Mathematics and Statistics. The lecturers of these subjects received technical support from the Eclips team members to create the video tutorials. This turned out to be quite beneficial for the content in general and the pace at which the content of the learning channel was created in particular. Even though these four subjects received priority, lecturers of other subjects were also invited to create video tutorials. In the second academic year of the project (2018-2019), the focus shifted to the courses of the second year bachelor, in order to finish the main development part of the project in 2019-2020 with a focus on the third year bachelor. This time path was selected to ensure that the content of the learning channel would gradually grow in a synchronous way with the students who started their academic life at the same time the learning channel was launched. The students can consult the learning channel during their entire academic career at the University of Antwerp.

The content of Eclips consists of both external video tutorials and in-house made videos. The external video tutorials are carefully selected by the lecturers, keeping the quality of the video tutorials in mind. These include video tutorials from websites like *Khan Academy* and *PatrickJMT*, and the above mentioned e-learning course from *Epigeum*. For in-house video tutorials, the faculty provides a recording studio where lecturers can record video tutorials with the assistance of an Eclips team member. Various types of recordings are possible in order to realize a variety of content types in the learning channel. Examples of these types are video tutorials making use of a glassboard, handwritten video tutorials, PowerPoint presentations, and green screen recordings. The type of the recording depends on the preference of the lecturer and the topic of the video tutorial. The current number of available video tutorials for each learning track is shown in Table I, and will be discussed in the next section.

D. Design

The user interface and experience are crucial with respect to the perceived ease of use, and therefore a critical success factor related to usage of this video platform by the students and lecturers. Together with the graphical design team of the University of Antwerp, a logo, a set of icons, and a comprehensive house style were designed. The icons are used in the mindmaps in which the students navigate through the structure. The logo makes it possible to brand both not only the in-house made video tutorials, but also the *Eclips*learning channel as a whole. Even though Blackboard is the platform that is used to publish the learning channel, the mindmaps, logo and icons give it a refreshing and contemporary look.

In order to make sure that the in-house video tutorials, made by different lecturers, exhibit a uniform look and feel, these in-house made tutorials start with the Eclips introduction screen, represented in Figure 3. To provide maximum support,

Figure 3. Example introduction screen.

a template for PowerPoint and Camtasia, i.e., a video editing program, were created. The main colour used in the templates is green, since this colour is used to represent the faculty within the university. The various learning tracks have different unique colours to identify them.

V. Adoption and Growth

In this section, we present some data regarding the available content and usage of the learning channel. We distinguish between the initial phase, corresponding to the first academic year after the launch, and the second academic year.

A. Initial Content and Use

The main realization is of course the mere fact that the faculty developed a dedicated, visually attractive learning channel, offering both in-house and external video tutorials and digital modules, and providing a clear structure in which the students can easily navigate. However, the actual success of the project is related to the adoption of the learning channel, and needs to be expressed in terms of content created by the lecturers, and usage of the video tutorials by the students. Table I shows

TABLE I. Number of video tutorials or digital modules in Eclips.

Learning track	In-house	External	Total
Business communication	7	6	13
Research methods and tool	11	10	21
Quantitative methods	43	108	151
Business economics	58	0	58
Economics	15	0	15
Total	**134**	**124**	**258**

the number of video tutorials and digital modules, that were available for each learning track in May 2018, less than one year after the launch of Eclips. Only the learning tracks that actually contain content are mentioned in Table I. In Figure 4, the growth of the offering in the different phases of the project is summarized. This figure shows that especially after the launch of the learning channel, the available content in general, and the production of in-house made video tutorials in particular, started booming. The highest growth rate is located in the learning track quantitative methods. This is both logical and desirable from a pedagogical point of view, since the content of quantitative methods covers the core competences that are prerequisites for other learning tracks.

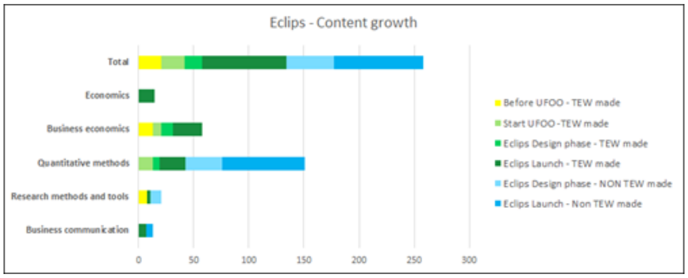

Figure 4. Eclips Content growth.

Through the *Mediasite* of the university, the video platform in which the in-house made videos are uploaded and made available, the lecturers can consult statistics on the views of their video tutorials. It gives an overview of how many students have watched the videos, which parts of the video have been watched the most, etcetera. In other words, it offers the lecturer a clear insight in the topics that students find more relevant and therefore consult accordingly. These results are, up to May 2018, less than a year after the launch of Eclips, summarized for the various learning tracks in Table II.

TABLE II. NUMBER OF VIEWS FOR THE VARIOUS VIDEO TUTORIALS.

Learning track	Number clips	Total views	Average views
Business communication	7	269	38
Research methods and tool	11	1232	112
Quantitative methods	43	8140	189
Business economics	58	59327	1023
Economics	15	2639	176
Total	**134**	**71607**	**534**

B. *Continued Use and Growth*

During the second academic year (2018-2019), the development of video tutorials continued. As mentioned before, the main emphasis was on courses for the second year bachelor, though tutorials for other courses were developed as well. An overview of the available video tutorials at the end of Septemer 2019, and their distribution over the various learning tracks, is represented in Table III.

TABLE III. NUMBER OF VIDEO TUTORIALS IN SEPTEMBER 2019.

Learning track	In-house	Growth	External	Total
Business communication	8	+14.29%	6	14
Research methods and tool	31	+181.82%	10	41
Quantitative methods	49	+13.95%	113	162
Business economics	76	+31.03%	0	76
Economics	22	+46.67%	0	22
Total	**147**	**+26.72%**	**113**	**260**

The growth percentages for the in-house made video tutorials clearly show a positive evolution in the adoption of the learning channel from the side of the lecturers. Moreover, we see a very strong growth in the learning track for research methods and tools. This is in accordance with the strategy to focus on the second year bachelor during this second academic year of the learning channel project, as that learning track exhibits no courses in the first year bachelor.

During this second academic year, it was also decided to create public channels on *YouTube* for three learning tracks, i.e., quantitative methods, business economics, and economicsm and to publish a number of video tutorials from these learning tracks on these public channels. Some numbers on the usage of these public channels are presented in Table IV. We make a distinction between the total amount of views on the *YouTube* channels (column 1 and 3), and the views originating from Blackboard and coming certainly from our students (column 2 and 4). Moreover, these figures are presented on a yearly basis ('Y', column 1 and 2) for the 12 months leading up to September 2019, and on the basis of monthly averages ('M', column 3 and 4).

TABLE IV. NUMBER OF VIEWS ON YOUTUBE SEPTEMBER 2019.

Learning track	Total-Y	Student-Y	Total-M	Student-M
Quantitative methods	20524	4684	1710	390
Business economics	58335	18019	4861	1502
Economics	288	29	24	2

Table IV shows that the adoption of the learning channel from the side of the students is evolving in a positive way as well. In order to gain more insight in this adoption by students, a survey was performed at the end of the examination in a number of courses, i.e., European Environment, Marketing Policy, Economics (both for Business Administration and Social Economics students), Macro-Economics, and Mathematics (for Business Engineering, Business Administration, and Social Economics students). The students were asked whether the Eclips learning channel was either *Known* or *Unnown* to them, and/or whether they viewed video tutorials from the learning channel *Often*, *At all*, or *Never*.

TABLE V. RELATIVE AWARENESS AND USE OF ECLIPS BY STUDENTS.

Course	Known	Unknown	Often	At all	Never
European Environment	76,7	23,3			
Marketing Policy	79,7	20,3			
Economics (BA)			11,1	23,3	65,6
Economics (SE)			24,3	34,5	41,2
Macro-Economics			1,5	15,7	82,7
Mathematics (BE)	95,9	4,1	15,8	57,5	26,7
Mathematics (BA)	83,2	16,8	5,3	26,4	68,3
Mathematics (SE)	80,4	19,6	19,4	42,4	38,2

Once again, these results, presented in Table V, were quite satisfactory from an adoption point of view. It is also worth noticing that the highest adoption rate is found in the course on *Mathematics*. As this is a difficult course with a low pass rate, it seems that Eclips is certainly perceived to have an added value during the study process. Moreover, the adoption rate is the highest for the *Business Engineering* students, who are widely considered to be the top students of the faculty.

VI. Toward new Value Networks

As e-learning technologies are often considered to be disruptive [2], they have the potential of disrupting existing value chains, and can therefore be threatening to academic faculties and institutions. However, this disruptive nature entails opportunities as well, as it could enable academic faculties to develop new value networks. In this section, we discuss some synergies and collaborations that have been developing as part of the *Eclips* project.

A. Synergies with Other Faculties

Since the launch of Eclips in September 2017, two other faculties of the University of Antwerp started with the implementation of their own tailor-made learning channel. These additional faculty channels share the *Eclips brand*, including the concept and the graphical design. Moreover, these channels exhibit the same structure and navigation based on learning tracks. In general, they offer parts of the content from the original channel, i.e., mainly in the quantitative methods learning track, but contain one or more additional learning tracks with video tutorials dedicated to specific courses offered in the degree programmes of these faculties. This interfaculty cooperation clearly offers multiple opportunities for the future. Such opportunities range from simple economies of scale for recording equipment, to the exchange and co-creation of video tutorials and/or scripts. An additional benefit is that the mere fact that the channel is being replicated in other faculties, has a positive impact on the *perceived usefulness* of the channel, and therefore on the adoption [10].

The development of the Eclips initiative into multiple learning channels for several faculties also implies an increase in efforts to manage the Eclips channel(s). For instance, the regulations concerning copyrights should be taken into account. Using video excerpts or short videos as educational resources without adding changes in a protected learning environment is allowed by Belgian legislation. However, referring or linking to the existing tutorials on the external channels should be done very carefully. Moreover, a growing learning channel consisting of three subchannels, needs permanent maintenance and monitoring. Due to the interaction with different parties delivering video tutorials, this may become quite challenging.

B. Reaching Multiple Target Groups

It is part of the mission of any university to connect to and interact with the outside world. In 2018, the faculty included the pre-students as second target group for the in-house produced tutorials. Three public subchannels, i.e., in the domains of mathematics, statistics and accountancy, were launched on *YouTube*. This was done to increase the *perceived ease of use*, and to connect to pupils of secondary schools and their teachers. The video tutorials are offered to provide this new target group with a tool to bridge possible knowledge gaps between secondary school and university before entering the university. As such, these tutorials will help pre-students to assess their readiness, and function as a support instrument in their study orientation process.

An additional benefit of these public channels is that they are also being consulted by students of other universities. Individual students have told us in interviews multiple times that friends of them, studying at other universities, view video tutorials on these public channels as well. Without doubt, the students showed a sense of pride while telling this, which will definitely have a positive impact on the *perceived usefulness*, and therefore on the adoption [10].

As lifelong learning becomes and remains a crucial issue in our society, the faculty recently decided to address alumni as a third target group of the Eclips learning channel. Specialized expert knowledge, based on research being done by academics, will be used to create video tutorials as well, serving both graduate students and alumni. Unlike the more accessible knowledge offered in the subchannel for pre-students, more advanced niche knowledge is targeted for the alumni subchannel. This channel is yet to be launched formally, but initial preparations have already begun.

Figure 5 presents a schematic overview of the various Eclips (sub)channels, with their the corresponding target group, i.e., pre-students, students, and alumni. For every individual target group, the technological hosting platform and the type of content are included in the summary as well. As an illustration, the QR codes referencing the different pre-student channels are also included in the representation.

C. Possible Future Collaborations

Reaching out to pre-students and alumni could both lead to collaborations with other organizations, and therefore new value networks. The interaction with pre-students in secondary schools for instance, could lead to more formal collaborations with these secondary schools and their teachers. Several secondary school teachers have already confirmed to be interested in producing their own dedicated video tutorials. This would allow them to take advantage of the facilities and competencies offered by the *Eclips* team and platform, and to collaborate on the content with other secondary schools that are part of the university network.

The interaction with alumni on the other hand, could lead to more formal collaborations with their employers. Organizations could for instance be interested to tap into video tutorials for basic courses that are relevant for certain groups of their employees. Another type of possible content partners are the spin-off companies of the university. A few spin-off companies have already expressed an interest to build upon university research video tutorials, in order to develop e-learning content for some of their products which are actually based on research that was performed at the university.

VII. Conclusions

In this paper, we have given an overview of the design, development, and initial adoption of the *Eclips Learning Channel*, providing video tutorials for the students of the *Faculty of Business and Economics* of the *University of Antwerp*. This development proofs that a single faculty can indeed build a digital learning channel with a perceived added value, using limited human resources, i.e., three part time team members, and elementary technological resources, i.e., Blackboard and PowerPoint. It also proves that taking into account upfront issues related to the adoption of such *Technology Enhanced Learning* techniques, can indeed foster a controlled and positive adoption of such a learning channel.

We have shown data on content and usage, indicating a clear positive evolution in the adoption of the *Eclips* learning channel at both sides of adoption, i.e., lecturers and students.

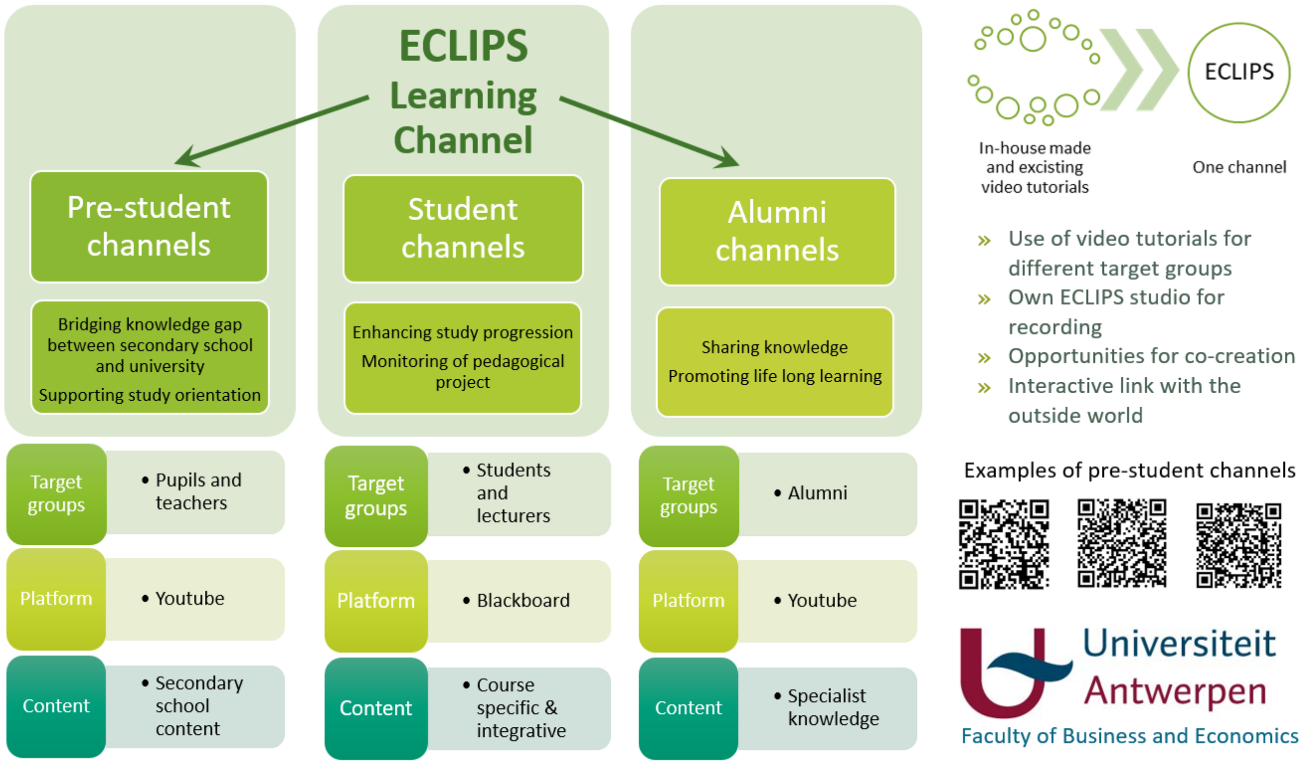

Figure 5. Schematic representation of Eclips (sub)channels and various target groups.

From the side of the lecturers, this adoption can be seen in both the amount of video tutorials produced in the initial phase, and the continued growth during the second academic year. At the side of the students, several numbers indicate a positive adoption of the learning channel as well. The number of views during the first academic year was clearly satisfactory, and continued to improve during the second academic year. Moreover, a survey has demonstrated that both awareness and usage of the learning channel by students is good to very good.

Another realization of the learning channel is that it is being adopted from two external parties at different adoption sides. First, two other faculties of the university decided to replicate the entire concept of the Eclips learning channel, and adapted the mindmaps to make a logical structure for their own faculty. Second, we have evidence that a number of students from other universities use the video tutorials while studying their courses. Both instances of external adoption contribute to the perceived usefulness of the initiative, and should therefore create an additional positive impact on the adoption.

Two academic years after it has been launched, there is ample evidence that the learning channel continues to gain momentum. However, the ultimate goal of the learning channel is of course to improve the study efficiency and results from the students. Though there are some preliminary indications that the learning channel has a positive impact on the student efficiency, such as informal conversations and the increased usage, there is no conclusive evidence yet for this. Therefore, we are planning to perform in the near future a quantitative study to gather evidence for a positive correlation between the use of the learning channel and the study results.

Finally, we have stated that e-learning initiatives like the *Eclips* learning channel, should take advantage of the potentially disruptive nature of e-learning technologies to establish new value networks. Though we have only just started to reach out to other target groups, i.e., pre-students and alumni, we have already explored some possible collaborations with secondary schools and (spin-off) companies.

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Comparison of Single Image Processing Techniques and Their Combination for Detection of Weed in Lawns

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***Abstract*— The detection of weeds in lawns is important due to the different negative effects of its presence. Those effects include a lack of uniformity and competition for the resources. If the weeds are detected early the phytosanitary treatment, which includes the use of toxic substances, will be more effective and will be applied to a smaller surface. In this paper, we propose the use of image processing techniques for weed detection in urban lawns. The proposed methodology is based on simple techniques in order to ensure that they can be applied in-situ. We propose two techniques, one of them is based on the mathematical combination of the red, green and blue bands of an image. In this case, two mathematical operations are proposed to detect the presence of weeds, according to the different colorations of plants. On the other hand, we proposed the use of edge detection techniques to differentiate the surface covered by grass from the surface covered by weeds. In this case, we compared 12 different filters and their combinations. The best results were obtained with the Laplacian filter. Moreover, we proposed to use pre-processing and post-processing operations to remove the soil and to aggregate the data with the aim of reducing the number of false positives. Finally, we compared both methods and their combination. Our results show that both methods are promising, and its combination reduces the number of false positives (0 false positives in the 4 evaluated images) ensuring the detection of all weeds.**

Keywords- Grass lawns; weeds; image processing; RGB bands; edge detection; drone.

I. INTRODUCTION

In order to maintain a great appearance in grass surfaces, certain requirements need to be addressed. The use of technology can help in its monitoring [1]. Due to the activities that are carried out on the grass or around it, the grass suffers from compaction and the leaves are broken. Some of the activities performed on the lawns in residential areas or in public gardens are certain sports, entertainment, and enjoyment. The users of the lawns demand a series of requisites, being the most important one the visual aspect of the lawns. The visual aspect can be expressed as the uniformity of the lawn, the greenness of the grass and the absence of grass patches. Moreover, the lawns should be maintained with a low level of inputs [2].

The existence of weeds in the lawn is a problem. On the one hand, the weed presence implies a lack of uniformity on the surface. This lack of uniformity is the first cause of disappointment for users. On the other hand, the weeds will generate competition between them and the grass species. For this reason, it is necessary to carry out specific actions to solve the weed problem as soon as possible. Despite the fact many studies showed the benefits of spontaneous plants in the urban lawns, users still prefer the uniformity of the grass [3-5].

It is crucial to detect the appearance of weed during the first days. Otherwise, the weed can infest huge areas of the lawn, and it will be difficult to eradicate them. Nowadays, the best available techniques to detect weeds are aerial images or the visual inspection of the lawns. The first option, the use of satellite images, offers multispectral images. Nonetheless, they have small spatial resolution and small temporal resolution. Thus, when we detect the weeds with the satellite image it may be too late and it would be necessary to apply the phytosanitary treatment to a large area. The second option, the visual inspection, is useful for small areas like a private garden. Nevertheless, for big areas like golf courses or big public gardens, this solution is not applicable. Therefore, the use of images obtained with drones and their analysis can be a solution for large surfaces [1]. The use of image processing is widely used in many different areas and for countless purposes. In agriculture, it has been used for illness detection [6] and for fruit maturity evaluation [7]. In aquaculture, it has been used for feed falling detection [8]. Moreover, it is used for face detection [9] and car license plate identification [10].

The aim of this paper is to present the use of image processing techniques for detecting the presence of weeds in lawns, which will be part of a system for garden monitoring described previously in [11]. Thus, a series of images were obtained from different lawns with the presence and absence of weed. The images were taken under different solar conditions. Different grass species and different weed species appear in the images. Part of the images will be used to evaluate the different techniques and methods included in our system and the rest of them to verify our findings. Two methodologies are tested, the Red-Green-Blue (RGB) band combination (or RGB methodology) and the edge detection filters. The goal is to use this methodology to automatize the monitoring of lawns in terms of weed detection. Therefore, it will be possible to detect the weed and apply the phytosanitary products only in the affected area. The operation of applying the phytosanitary product is not the focus of this paper. First, we test each methodology, including pre-processing to remove the soil from the analysis and post-processing to minimize the number of False Positives (FP). Then, we compare the results of both techniques and their combination.

The rest of this paper is organized as follows. Section II presents the related work. Section III describes the proposal. The methods, band combination and edge detection are described in Section IV. Section V addresses the obtained results of each separated methodology and its combination. Section VI summarizes the conclusions and future works.

II. Related Work

In this section, we are going to compare other techniques utilized to detect weed in different crops.

The detection of weeds is an important issue for agriculture. Therefore, many scientists have been working on their identification based on images. The use of drones has increased the possibilities, and in recent years several papers have been published.

The use of image processing to determine the presence of weeds in maize fields was presented by Burgos-Artizzu et al. in 2011 [12]. They described a computer vision system that can be used with videos. They tested their system under different light conditions. The system detected 95% of the weeds and 80% of the crops.

Paikekari et al. presented in 2016 [13] an image processing methodology for weed detection. First, they used color to differentiate soil and grass. Then, the resultant image was converted into a greyscale image to apply an edge detection technique. Finally, the resultant image of edge detection was divided into 25 blocks. The analysis of each block determined if it contained weed with narrow leaves, weed with wide leaves, or crop.

In 2018, Gao et al. [14] presented the use of aerial images with an ultra-high-resolution to detect intra and inter-row weed. They used a semi-automatic object-based image analysis with random forests. In addition, they used techniques to classify soil, weed, and crop. The authors applied this proposal to maize crop fields. The utilized images show the maize in the first days of growth. Their results have a coefficient of correlation of 0.895 and a mean squared error of 0.026.

Marín et al. in 2017 applied simple image processing techniques in different publications to detect the grass coverage in lawns [15][16]. They worked with the histograms of the grass images to determine the weight of the grass and the level of coverage (high, low, very low).

On the other hand, there are other types of studies focused on identifying different leaf affections. One example is the work developed by Khanaa and Thooyamani in 2017 [17]. They proposed an algorithm based on image processing. Their algorithm was able to detect different leaf diseases, such as bacterial pith necrosis, early blight, white trail, and target spot among others.

Finally, Parra et al. in 2019 [1] showed the use of a new form of weed detection based on photographs taken from drones. In their article, they used the combination of pixel values in the three bands (RGB) to differentiate different types of surfaces (soil, grass, and weeds). Their results were promising and offer different types of formulas depending on the needs with different percentages of false positives (FP) and false negatives (FN).

III. Proposal

In this section, we are going to detail the proposed system for lawn monitoring. The system is composed of a drone that flies over the lawn and takes photos. Then, the images are evaluated to determine where there are weeds in the lawn to program the application of phytosanitary products.

A. Drone

Our system uses a drone to take images of the lawn. Since we need a spatial resolution of 1mm we should select a drone with a camera that has a high spatial resolution and flies at high height altitude. Nevertheless, we can select a drone with a camera that presents lower spatial resolution and flies at a lower height. In order to calculate the flying height according to the camera resolution, we can use the equations proposed by Marin et al. [16]. We are going to use an Arduino camera with 640X480 pixels, and the flying height will be 2.3m.

It is important to note that for our proposal we are going to use a drone with no camera. We will add the above-mentioned camera connected to a Raspberry Pi 3 node. The Raspberry Pi 3 node will be in charge of taking images and analyzing them. Nonetheless, the flying issues will be operated by the drone processor, not by the Raspberry Pi 3 node. Thus, we can split the task into different processors and our system can be adaptive to different situations.

B. Operational principle

Once the images will be gathered by the camera installed on the drone, the same node will analyze them. We need a fast analysis because the processor should analyze the data during the flight in order to trigger the sprinklers of the phytosanitary products. Thus, it is necessary to focus on simple image processing techniques and use a node with high processing capacity. Therefore, we propose to use a Raspberry 3 to analyze the data.

Furthermore, we reduce our possibilities to the operations that involve only the RGB data of each pixel in the image. Therefore, we will avoid image recognition techniques. This type of technique, image recognition, offers accurate results. Nonetheless, they require higher processing capabilities and internet connection in some cases. On the other hand, the methods that use only the pixel values are common when we work with satellite images, which are multispectral images.

Our challenge is to detect weeds in the lawns with the combination of only three image bands, red, green and blue (RGB). We can use two different options for detecting the weeds, the first option is the mathematical combination of the pixel values of the bands. Thus, operating with the pixel values of the RGB bands we can obtain a new image composed of pixels, whose values are a linear combination of the previous bands. Due to the fact that the soil, grass, and wild species have different coloration, this is a feasible option to differentiate the three surfaces.

The second option is to use a combination of the pixel value and their neighbors from a single band. There are several techniques that use this method and are known as edge detection. It is important to note that the edge detection techniques are applied to one of the RGB bands. Therefore, they work with images in black and white. Edge detection techniques include different mathematical methods aimed to identify points in an image at which the brightness changes sharply. Since the aspect of grass and wild species are different, they will generate different patterns of brightness changes. The grass is composed of small and sharp leaves while most of the wild species have wide leaves. Therefore, the areas covered by grass will present more changes than the areas covered by wild species.

The proposed system is shown in Figure 1, we can see the different bands obtained and their names. The red, green and blue bands of the image are also known as band 1, band 2 and band 3.

C. *Studied lawns*

The proposed system was tested in Finca El Encin, research facilities of the Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario (IMIDRA) in Spain. There are small experimental plots where other scientists are testing multiple grass combinations. During their research, different weeds appear in their lawns. We use their experimental plots to take images of different types of lawns with and without the presence of weeds.

By using these experimental plots, we ensure that we will have lawns with different types of grass and under different environmental conditions. The plots used in the first step can be seen in Figure 2.

In order to have verification, other images were taken in a different scenario. These images were gathered in Gandia, Valencia (Spain) in the gardens of Universitat Politécnica de Valencia (UPV). We intend to have a combination of images with and without the presence of grasses to test the system performance in terms of FP, FN, true negatives (TN) and true positives (TP).

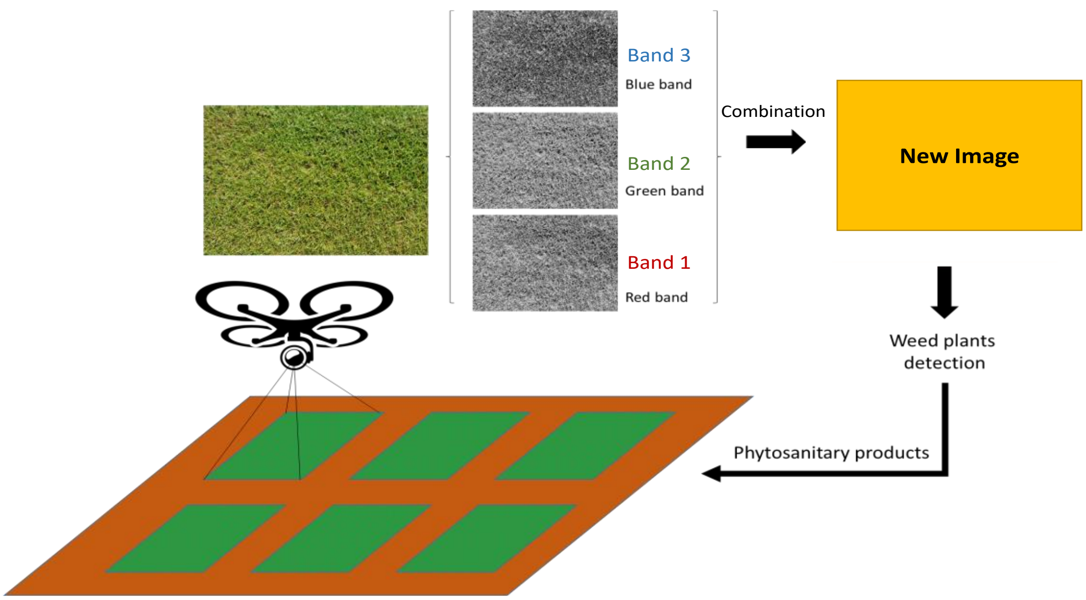


Figure 1. System description.

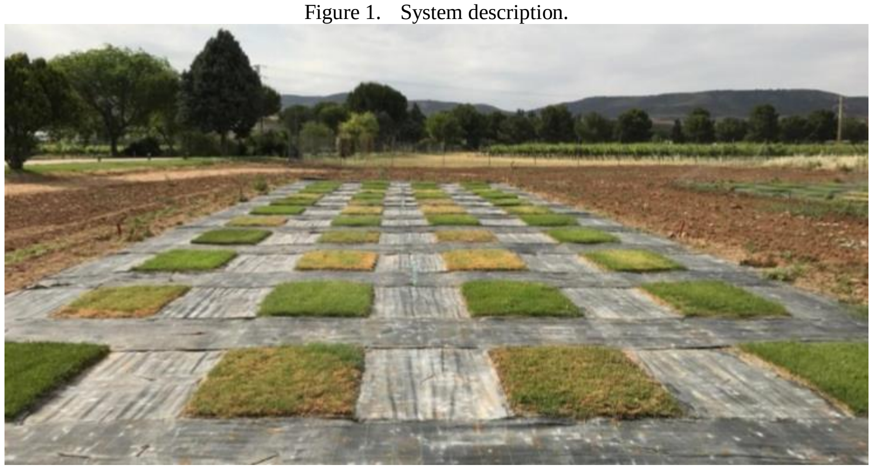


Figure 2. Lawns image

Moreover, we include images with different illumination conditions and with shadow areas to evaluate the possible negative effects. The characteristics of the used cameras are summarized in Table I.

IV. METHODOLOGY

In this section, the methodology for the image analyses is described. First, we describe the operations applied before the use of the proposed techniques, also known as pre-processing. Following, the technique of RGB combination is described. Subsequently, the edge detection techniques are detailed. Finally, post-processing is established.

A. Image pre-processing

In this subsection, the steps for image pre-processing are described in detail. The first step is the clipping of the image. The aim of this step is to ensure that all the pixels of the image are representing grass. This step is only used in the tests for evaluating the techniques. In the used images there are some external objects like architectonic elements (streets, park benches, and tarpaulins). Once the techniques are used in the real system, the gathered images will be only taken in the grass area of the garden and no other architectonic elements will appear. Therefore, this step is performed manually.

The next step is to extract from the image the areas covered by dead grass or soil (areas of the garden without grass coverage). The objective is to avoid FP in the areas of soil. This is especially important in the case of edge detection. For this purpose, we are going to use the linear combination of RGB values of the pixels to differentiate the areas covered by healthy grass from the areas covered by soil or dead grass.

As a result, we will obtain an image that solely contains the areas covered by healthy plants (grass or weed species). Now, the obtained image is ready for being processed.

B. Image processing: RGB combination

In this subsection, the details of the RGB combination for detecting the presence of weeds are described.

The first issue to be considered is that it is not possible to work with threshold values of only one of the layers. Because these values are greatly affected by sun exposure, the presence of clouds, and even the day of the year. Thus, we need to work with a mathematical combination of different bands to avoid this problem.

The second issue is related to the values of the pixels. Each pixel has a value between 0 and 255 in each one of the bands. The value is directly related to the brightness of the pixels. The pixels with higher values are represented in lighter colors. Meanwhile, the pixels with low values are displayed in darker colors. The areas with green color will have high values in the bands of green and lower values in the blue and red bands.

The value of the pixel has no decimals and can only have a positive value. When we are applying the mathematical combinations, these rules are maintained. The resultant value of each pixel will be a positive value with no decimals. When mathematical operations are used, the maximum value can exceed the value of 255.

The objective of this step is to obtain a new image where the values of pixels belonging to grass coverage are different from the values of pixels belonging to weed coverage. Therefore, we will explore the differences in the values of weed and grass in each band and find a simple mathematical expression that maximizes these differences in the resultant bitmap image. We will use different mathematical combinations of the bands to obtain a new image with low values in the areas covered by grass and high values in the areas covered by weeds.

C. Image processing: Edge detection

In this subsection, the information of the edge detection methodologies is described. There are many techniques for edge detection and we are going to describe the basics of the used ones.

All the used filters can be used individually, but some of them offer better results when they are combined. For example, the gradient filters or the line detection filters. In this case, the four available filters are used individually. Then, the resultant image of each filter is combined (by adding the values of the individual images) having, as a result, a new image.

The most important thing to know is the fact that these tools help us find the points of the photograph where there is a change in pixel values. Generally, these zones represent the edges of an object or, in our case, of a leaf. To detect this change, a mathematical operation is performed with the value of the pixel and its closest pixel, called neighbors. The operation to be performed will depend on the specific tool, or filter, used. Most of them use the value of that pixel (PI) and its 8 nearest neighbors (N1, N2, ..., N8) for the calculation of the new value assigned to this pixel, forming a 3x3 matrix, as can be seen in Figure 3.

TABLE I. CHARACTERISTICS OF UTILIZED CAMERAS

Characteristics	Images in IMIDRA	Images in Gandía
Size of the image	2048x1536 pixels	4032x3024 pixels
Horizontal and vertical resolution	72 ppp	72 ppp
Bit Depth	24	24
F point	f/7.1	f/1.7
Focal distance	5mm	4mm
Exposure time	1/400 s	1/100 s
ISO Velocity	ISO - 125	ISO - 80

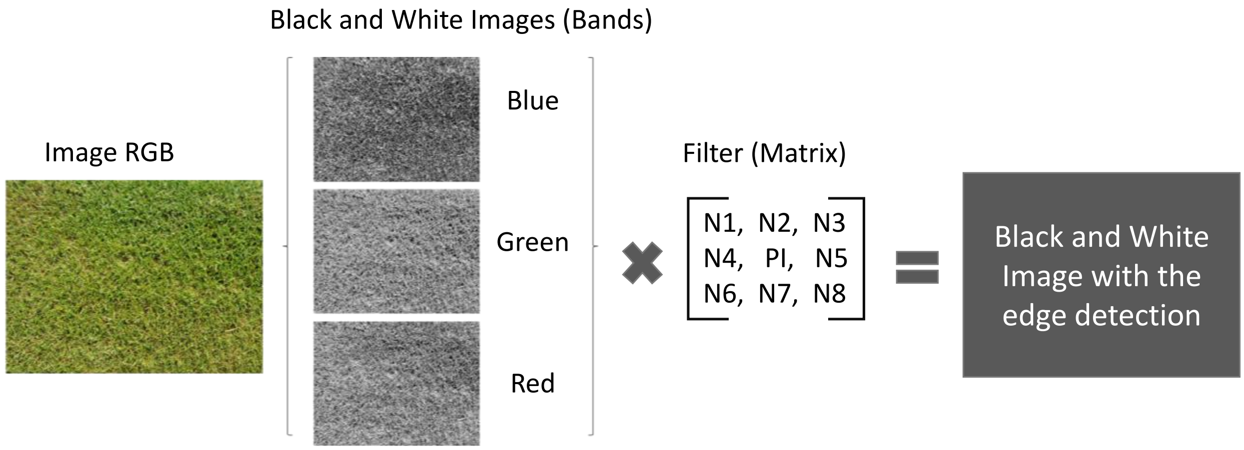


Figure 3. Use of filters in the image

Whichever filter is used, the result will be a new image in black and white where pixels that are not edges will have very low values, close to 0. Meanwhile, pixels that represent a zone of change, which is an edge, will have high values. There is no maximum value, the values will be higher or lower depending on the filter used. Our goal will be to find the areas of the image that have very low values. In the images taken, the areas covered by grass have numerous edges, while the areas where there are weeds are areas with greater uniformity in the pixels. Therefore, the areas with low values after the application of filters will represent the areas with weeds. Following, we detail the filters that have been used in this study.

First, there are the edge detection filters, among which we find: the gradient filters, Laplacian filter, line detection filters, and Sobel filter. There are other edge detection filters but those are the ones we are going to use in the study.

Gradient filters are the best when we want to detect edges in increments of 45º. Based on this type of filter we find the north, east, south, and west gradient filters.

Secondly, we will use the Laplacian type filters. We will use only one of the variants, the one which uses a 3x3 matrix. This filter is useful for detecting edges, whatever the orientation of the edge. The Laplacian filter is recommended for the enhancement of linear features, especially in urban environments.

The next filter used is the line detection filter, very similar to the gradient filter. There are four variants of this filter, according to the direction in which the edges are highlighted, vertical line, horizontal line, left diagonal line and right diagonal line.

The last type of edge detection filter is the Sobel filter. Since the matrices used by these filters are identical to some used in gradient filters, Sobel filters are not included. All edge detection filters use a 3x3 matrix as can be seen in Figure 4.

On the other side, there are the sharpening and smoothing filters. In our case, we will use only those of sharpening. The smoothing filters will be used later on for other purposes. The sharpening filters are recommended to be used so as to highlight the comparative difference of values with their neighbors. They allow us to enhance the boundaries between objects in the photographs. In this case, and despite the existence of other filters in our study, we have included only three of them: two filters that use a 3x3 matrix and a 5x5 matrix, which can be seen in Figure 5.

D. *Post-processing*

Finally, to ensure the selected areas belong to wide leaves of weeds and minimize the FP, we apply an aggregation technique. These techniques are described in this subsection.

Aggregation techniques allow, first of all, the combination of the value of a pixel and its neighbors, resulting in a new pixel; and secondly, increasing the size of the new pixel. The value of the new pixel, as well as its size compared to the previous pixels, will depend on the technique we use. There are different types of aggregation techniques. We can use different types of mathematical operators, such as maximum, minimum, median, mean, or even summation. Then, the size of the cell must be defined. The bigger the cell is, the higher the number of pixels will be used for the mathematical operator. Thus, the resultant pixels will be bigger than if we select a small cell.

In the case of the RGB combination, the objective is to find a group of pixels with high values and avoid FP due to an isolated pixel with high value. Those isolated pixels with different values are generally related to light sparkles in the leaves of grass or due to errors in the image. As this type of pixels usually appears isolated, the possibles FPs are easily corrected with the aggregation technique, since their neighbors have regular values (belonging to grass or to weeds). Therefore, to detect the presence of a group of pixels with high value we will use as aggregation technique the mathematical operator of minimum, mean and median. Thus, if an isolated pixel has a high value (without belonging to weeds), once the mathematical operation is performed the resultant value will be lower due to the low values of its neighbors. However, when a group of pixels (belonging to weed leaves) have a high value, when the mathematical operation is done the resultant pixel will have a high value. We will test as aggregation cell value the sizes of 3, 5 and 10.

In the case of edge detection, we seek to identify areas that have a group of pixels with low values. Thus, we will use the sum of all the pixels and the maximum value of the included pixels as an operation to calculate the value of the new pixel. As for the resulting pixel size, or cell size, we use the values of 3, 5 and 10.

With the obtained image from the aggregation technique, threshold values must be taken to differentiate the pixels we consider positive (weeds) and negative (grass). There are different techniques to do it. In previous papers, the one which has shown a better result in changing lighting conditions has been the creation of classes based on statistical parameters. This option offered better results than taking a threshold value and applying them to all cases as was done in [10].

To sum up the whole process we have created a block diagram that represents all the steps carried out in this paper. The part of pre-processing is not included. The flow is presented in Figure 6.

North Gradient
$$\begin{bmatrix} -1, & -2, & -1, \\ 0, & 0, & 0, \\ 1, & 2, & 1, \end{bmatrix}$$

East Gradient
$$\begin{bmatrix} 1, & 0, & -1, \\ 2, & 0, & -2, \\ 1, & 0, & -1, \end{bmatrix}$$

South Gradient
$$\begin{bmatrix} 1, & 2, & 1, \\ 0, & 0, & 0, \\ -1, & -2, & -1, \end{bmatrix}$$

West Gradient
$$\begin{bmatrix} -1, & 0, & 1, \\ -2, & 0, & 2, \\ -1, & 0, & 1, \end{bmatrix}$$

Laplacian
$$\begin{bmatrix} 0, & -1, & 0, \\ -1, & 4, & -1, \\ 0, & -1, & 0, \end{bmatrix}$$

Vertical Line
$$\begin{bmatrix} -1, & -1, & -1, \\ 2, & 2, & 2, \\ -1, & -1, & -1, \end{bmatrix}$$

Horizontal Line
$$\begin{bmatrix} -1, & 2, & -1, \\ -1, & 2, & -1, \\ -1, & 2, & -1, \end{bmatrix}$$

Left Diagonal Line
$$\begin{bmatrix} -1, & -1, & 2, \\ -1, & 2, & -1, \\ 2, & -1, & -1, \end{bmatrix}$$

Right Diagonal Line
$$\begin{bmatrix} 2, & -1, & -1, \\ -1, & 2, & -1, \\ -1, & -1, & 2, \end{bmatrix}$$

Figure 4. Used edge detection filters

Increase Sharpness
$$\begin{bmatrix} -0,25, & -0,25, & -0,25, \\ -0,25, & 3, & -0,25, \\ -0,25, & -0,25, & -0,25, \end{bmatrix}$$

Sharpness [3x3]
$$\begin{bmatrix} -1, & -1, & -1, \\ -1, & 9, & -1, \\ -1, & -1, & -1, \end{bmatrix}$$

Sharpness [5x5]
$$\begin{bmatrix} -1, & -3, & -4, & -3, & -1, \\ -3, & 0, & 6, & 0, & -3, \\ -4, & 6, & 21, & 6, & -4, \\ -3, & 0, & 6, & 0, & -3, \\ -1, & -3, & -4, & -3, & -1, \end{bmatrix}$$

Figure 5. Used sharpening filters

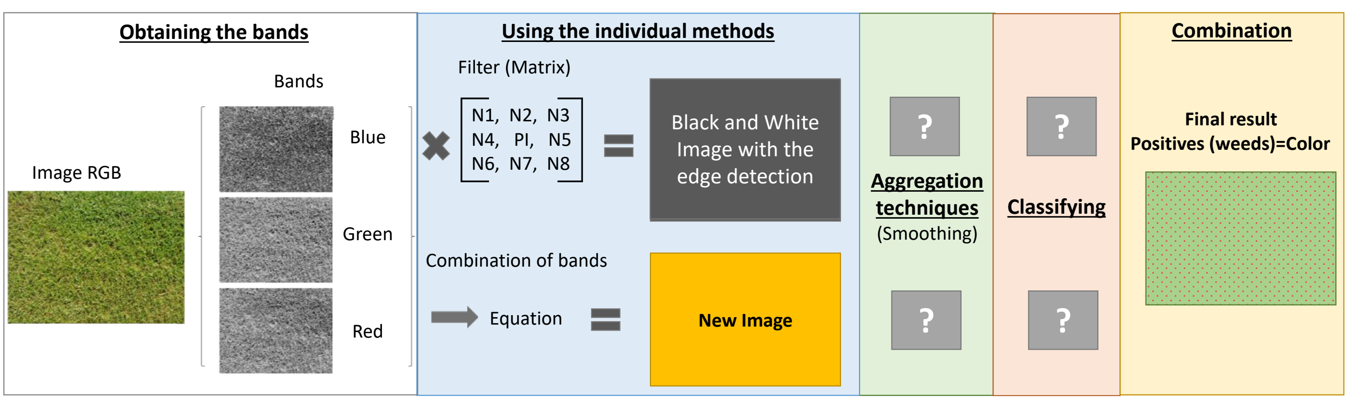


Figure 6. Block diagram of the followed steps

To evaluate the performance of the proposed methodology we will use the following parameters: (i) FN: we will consider how many weeds have not been indicated by any pixel after the analysis. (ii) FP: will be given as the total pixels that, according to the methodology used, indicate the presence of weeds although it is grass. (iii) TP: will be considered as the number of weeds that are indicated by one or more pixels.

V. RESULTS

In this section, we are going to show the obtained images and its processing to determine the presence or absence of weeds. First, we show the process to obtain the equations to detect the weed. Finally, we will present its verification.

A. *Image pre-processing: soil removal*

The image processing method is shown in this subsection. First, Figure 7 presents the RGB images in four different cases. The first one is a lawn with low grass coverage and with the presence of weeds at the top-center part. The weed has a darker coloration than the grass. Furthermore, it presents higher relative values in the blue band, compared with the rest of the grass. Image 2 is taken in a lawn with high grass coverage. There is a weed at the bottom-left of the image. As in the previous case, the weed has a more bluish coloration.

In Image 3, we can see a lawn with low grass coverage and with the presence of the weed in the bottom-right of the image. In this case, the weed has a more yellowish coloration, compared with the grass. Finally, Image 4 represents typical lawns with no weeds; but, under light water stress. Thus, there are some parts of the grass that have a yellowish coloration due to the lack of water.

The first issue that we can pay attention to is the fact that the soil has higher values of brightness in the red band than in the green band. Therefore, considering that the values of the pixels only can be positive and without decimals, we divide the green band by the red band obtaining a new image, which gives us information about the soil/plant coverage, see (1). The result of this mathematical relation between bands can be seen in Figure 6. The grass pixels have values higher than zero and are colored in green. The soil pixels have values of zero and are colored in yellow. Unfortunately, the portions of grass that have suffered from stress or have been strongly compacted, present a similar coloration than the soil. Consequently, those portions might be classified as soil. For our application, it is not a problem, because the important part for us is the green grass and green weeds.

$$Soil\ removal = {}^{Band\ 2}/_{Band\ 1} \quad (1)$$

B. *Image processing: weed recognition with RGB combination*

The next step is to find a mathematical relation, which gives, as a result, a new image with different values for pixels of grass and pixels of weed.

We have two different types of weed, the ones with more bluish color, and the ones with more yellowish color than the grass. Consequently, we will need two different equations to detect the presence of weeds. One equation for the bluish weed, the ones which appear in RGB Image 1 and RGB Image 2 of Figure 7. Another equation for yellowish weed, like the one which appears in RGB Image 3 of Figure 7, will be needed. The first equation, (2), will be used to detect the bluish weed. This resultant image after applying (2) will have high pixel values where there is a bluish weed. Thus, the equation has to maximize the data of pixels with higher relative blue values. Then, the data from the blue band should be divided by the data from the red and green bands. Since the dividend of the equation (blue brightness value of the pixel) has lower values than the divisor (green x red brightness values of pixels), and the pixels can only be a natural number, almost all the pixels have a value of zero.

Thus, no differences were found. In order to increase the value of the dividend, we square it. Nevertheless, the value of the dividend is still lower than the value of the divisor in the majority of the cases and most of the pixels have a value of zero in the resultant image. Finally, we cube the divisor. Then, we obtain a new image with different values for different coverage surfaces. The obtained image combination that is used to detect bluish weeds can be seen in (2).

On the other hand, we have an image with yellowish weeds. To detect them we should use the opposite steps than in the preceding paragraph, we have to use the data from green and red bands for the dividend and the data from the blue band for the divisor. As in this case, the values of the dividend are always higher than the values of the divisor, it is not necessary to neither square nor cube any of them. Therefore, the proposed formula, which can be used to detect the yellowish weed, is given by (3).

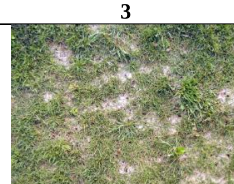
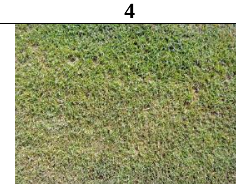
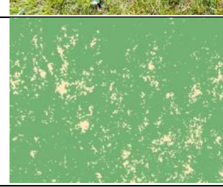
Image nº	**1**	**2**	**3**	**4**
RGB image				
Soil/Grass Coverage				

Figure 7. Images utilized to obtain equations for weed detection

$$Weed = \left({Band\ 3^3}/{Band\ 2\ \times Band\ 1} \right) \quad (2)$$

$$Weed = \left({Band\ 2\ \times Band\ 1}/{Band\ 3} \right) \quad (3)$$

The result of applying (2) and (3) to the RGB images of Figure 7 can be seen in Figure 8. We apply both formulas to all of the images to show the effectiveness of each formula for generating a new image that contains information about weed presence. The different colors represent different values in the image. The pixels with yellow tones have lower pixel values. On the contrary, the pixels with purple and blue colors have the highest values. In the RGB image, the presence of weed and its position are indicated with red circles.

As it is expected, the pixels that contain bluish weeds (RGB Image 1 and RGB Image 2 in Figure 8), present higher values in the resultant image after applying (2) than the pixels that contain grass or soil. The pixels of the resultant image that have higher brightness values are represented in purple and blue colors. Meanwhile, the pixels with low brightness values are colored in yellow and light yellow. We can see that Image 1 and the resultant image of (2) present higher pixel values, colored in blue, in the area where there are weeds. The resultant image of (3) presents higher values in the pixels that represent one of the grass species in Image 1. In Image 2, there is no specific area that contains pixels with high values.

For Image 3, we can see that the pixels of the image obtained with (2), which have the highest values, are not related to the presence of weeds. However, in the image obtained with (3), we can clearly identify the presence of the weed. We can see that one of the grass species present in the lawn of Image 3 is giving high values (red color). But the purple and blue colors are only related to the weed presence.

Finally, the resultant image of the image from the lawns without weed does not present any areas with high values. In the case of the resultant image of (2), there are some pixels with high values. Nevertheless, they appear scattered around the image, not joined in one area as in the other cases. Meanwhile, in the image of (3) almost all the pixels present low values and few pixels have high values.

As the higher values indicate the presence of weeds, to evaluate the aggregation technique we are only going to consider the pixels with the highest values. We will use the natural breaks, jenks, to divide the pixels into 5 groups and only the last group will indicate the presence of weeds.

One of the major advantages of the proposed system is that its results should not be affected by changes in solar exposition. Thus, we are going to test the aggregation technique with images gathered at another time period with different environmental conditions. Moreover, we are going to evaluate the use of a smoothing technique to reduce FP.

The used images and the results of the analysis of the aggregation technique can be seen in Figure 9. Again, the position of weed is marked with a red circle in the RGB image.

Image 5 of Figure 9 was gathered on a sunny day and represents a lawn with low grass coverage, with two types of soil (light and dark brown), and with the presence of a lot of weeds. Some of the weeds of Image 5 of Figure 9 are a bluish weed, then, the results are after applying (2). Image 6 of Figure 9 was taken on a day with less solar radiation. The image represents a lawn with some grass patches and the presence of yellowish weed at the bottom of the image. Therefore, the verification is done with (3). Finally, Image 7 of Figure 9 represents a lawn with regular grass coverage on a cloudy day. In Image 7 of Figure 9, no weeds are present, the results are obtained with (2). We select (2) because it is the one that gives more FP in the previous test. The results with the cell value of 10 have not been presented, because they were not representative. We are going to present the results of a cell value of 5.

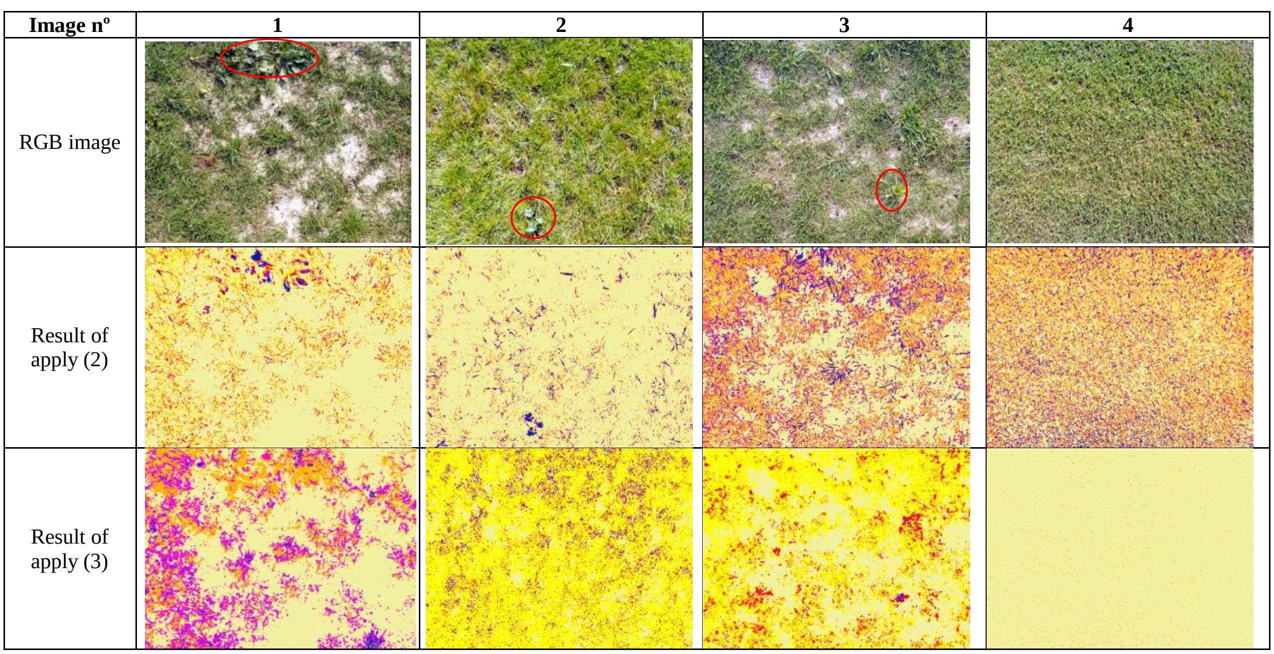


Figure 8. Images Obtained After Apply The Formulas Of (2) and (3) For Weed Detection

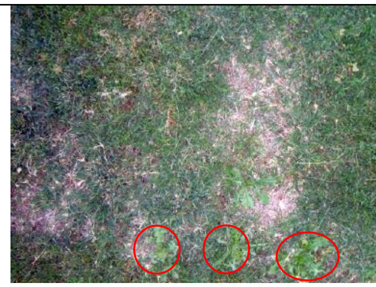
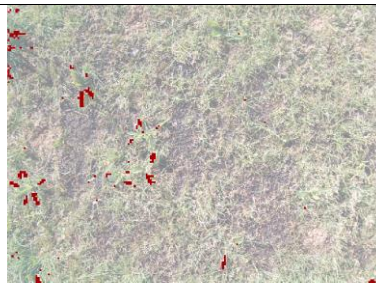
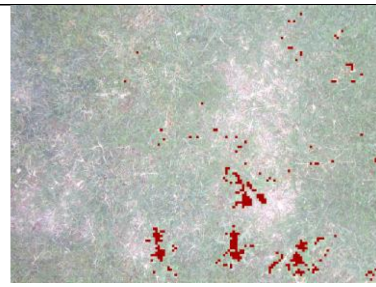
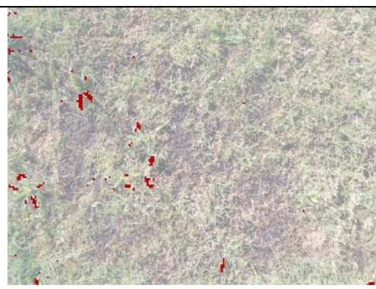
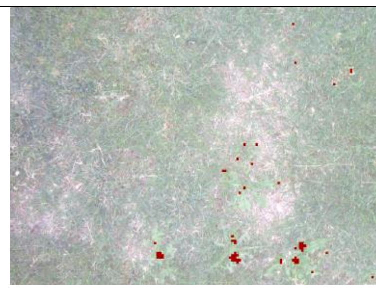
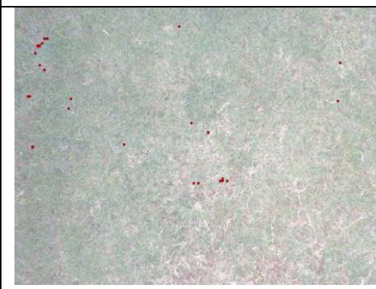
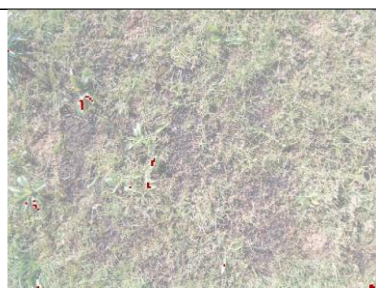
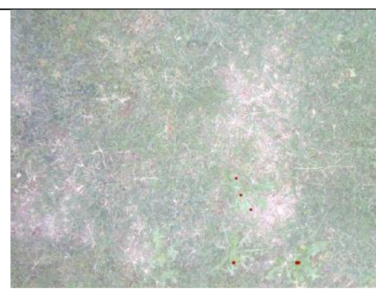
Image nº	5	6	7
RGB image			
Aggregate data: Cell size 5 Aggregation type: Mean			
Aggregate data: Cell size 5 Aggregation type: Median			
Aggregate data: Cell size 5 Aggregation type: Minimum			

Figure 9. Original images and obtained images in the verification process

First, we present the results of the aggregation technique, which uses the mean as a result. This technique is quite accurate in terms of identifying the leaves of the weeds. However, there are still some FP, which identify as a weed normal grass leaves, FP= 12, >40 and 22 in Images 5, 6 and 7. The FPs are more visible in the case of Image 7, where there was no weed. The number of FN is very low, FN= 1, 0 and 0 in Images 5 to 7. Finally, the number of TP is considerably high compared with the FN, TP= 5 out of 6, 4 out of 4 and 0 out of 0 in Images 5 to 7.

The results of using an aggregation technique with the median have less FP (FP=9, 11 and 21 in Images 5 to 7). In terms of FN and TP, the results of using the median value are the same as those of using the mean value.

Finally, if we use the minimum as a mathematical operator, the results show that FP=0 in all the images. Nevertheless, by utilizing this technique we have some FN (FN=3, 1 and 0 in Image 5, Image 6, and Image 7 of Figure 8).

Thus, depending on the application and the produced effects on the case of FP and FN, we can use one aggregation technique or other. For our application, since the objective is to maximize the grass quality by minimizing the phytosanitary products usage, we prefer to have FP than FN. Therefore, we propose to use the aggregation technique that uses the median as a result.

C. Image processing: weed recognition with edge detection

The results of applying the filters described in Figures 4 and 5 are detailed in these paragraphs. To set-up of the system we have used different images, see Figure 10. The images were taken at the same height, some of them represent gardens with grass. Furthermore, we include an image, Image 4 in Figure 8 and Figure 10, which contains grass and weeds.

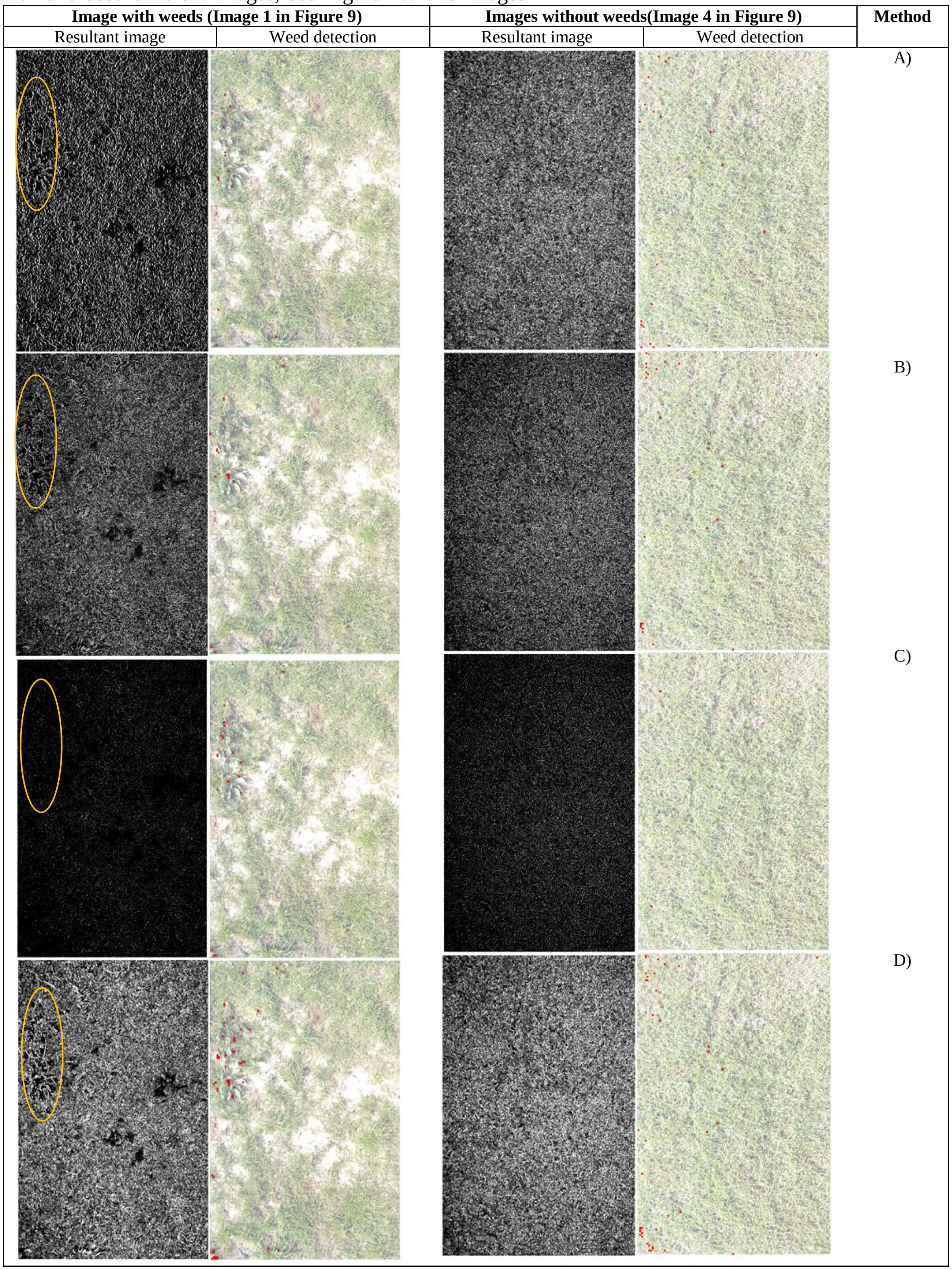


Figure 10. Image obtained after edge detection filters

We analyze the effectiveness of each filter presented in the previous section and the best results are shown. First, the best aggregation technique for all cases has been the sum with a cell size equal to 5. It has also been observed that there are no differences in the results when the filters are applied to the different bands (RGB) of the image. Therefore, the results shown in this section correspond to the use of the filters in the red band. The presence of weeds in Figure 10 is indicated with yellow circles.

Gradient filters, when used individually, have given very bad results. Despite applying aggregation techniques, the results did not clearly indicate the presence of weeds. However, when all the gradient filters are used together (each one applied separately and adding the 4 images obtained), the results markedly improve, see Figure 10 method A. The same behavior has been found with the line detection filters, by adding the images from the individual filters the results improve considerably (Figure 10 Method B).

In both cases, the presence of dicotyledonous weeds has been detected. In the case of the line detection filter, a monocotyledonous weed has been detected in the image with weeds (TPs = 4 in both cases). Conversely, in both cases, two of the weeds have not been detected, FNs = 2. Therefore, we have FNs, which would cause the non-detection of a wild plant. There is no case FP in the image with weeds. Regarding the image without weeds, both filters give a considerably high number of FPs, 20 with method A and 24 with method B.

In relation to the Laplacian filter (Method C in Figure 10), it has offered very good results without the need to be combined with other filters. Laplacian filter is the one that generates less FP when there are no weeds, FP = 2. In the case of the image with weeds, the results are equal to the previous filters, it has detected 4 out of the 6 plants, TP = 4 FN = 2.

Finally, the sum of the gradient filters plus the line detection filters has a great capacity to detect weeds (Figure 10 Method D). In the photograph with weeds, it is able to detect the presence of all of them, therefore it results in TP = 6. However, in this photograph, the combination of filters indicates the presence of weeds where there is no weed in two cases, FP=2, both of them located in shadow areas. On the other hand, its result in photographs without wild plants shows that it is the worst option with a total of 39 FP.

The sharpening filters have not given good results in any case, they give a high amount of FP and the TP are not as high as for the edge detection filters. Therefore, these filters have been excluded from the analysis.

It is necessary to consider that up to this point we have worked with the option of classifying the resulting images according to the standard deviation of the image data. However, it has been observed that in this case, the use of a threshold value would be more appropriate. In Table II we present the minimum and maximum values of the class that is considered positive in Image 1 and Image 4 of Figure 10. Therefore, we could propose a threshold value depending on the method like the maximum value of pixels characterized as a weed in the image with weeds and minimum value of pixels characterized as a weed in an image without weed. The following thresholds 75, 100, 18, and 100 are proposed for methods A to D. However, we need to compare the use of threshold values with the standard deviation to classify the pixel values when the light conditions change.

As the methodology that has given the best is C, Laplacian filter, we will check the results when using the threshold value proposed with the previous photographs to other new photographs obtained in Gandía. 3 out of 4 images have been taken in conditions of light similar to the photographs of the previous test (in IMIDRA) and the last one has been taken in conditions of lower light. Images 1, 2 and 4 have weeds, and Image 3 does not.

TABLE II. MAXIMUM AND MINIMUM VALUES OF PIXELS CHARACTERIZED AS WEED

Type of image	Values	Method A)	B)	C)	D)
Image without weeds	Minimum	96	138	19	187
	Maximum	147	214	26	357
Image with weeds	Minimum	0	36	10	36
	Maximum	67	90	19	79

In Table III we can see the results of the comparison of different classification options. In lighting conditions similar to the photographs used to obtain the threshold values, the use of the threshold value improves the results. The amount of FP is reduced in all cases by using the threshold value. The amount of FN has increased in one of the cases, this fact is not as worrying as the FP. We must consider that a FN in an image where the presence of weeds has already been detected has no repercussion since this area will be treated with the phytosanitary anyway. On the other hand, a FP in an image without weeds will cause an area to be treated without any need.

However, analyzing the data in Photography 4, which has been taken in conditions of lower light, we observe that the results of classifying based on the standard deviation are better than the results of the threshold. When classifying with the established threshold value the number of FP is almost 4 times higher. Therefore, threshold values must be generated for different lighting conditions, or use the standard deviation as a classification method.

TABLE III. COMPARISON OF CLASSIFICATION OPTIONS FOR METHOD C

Method	Parameter	Image 1)	2)	3)	4)
Standard deviation	VP	5	8	0	4
	FP	1	≈ 40	2	≈ 60
	FN	2	4	0	0
Threshold value	VP	5	4	0	2
	FP	0	0	1	≈ 200
	FN	0	8	0	2

D. *Comparison of both techniques*

Finally, we are going to use four new images, two without weed presence and two with weed presence, taken in the same location than images 1-4 to compare the performance of both methodologies.

With regard to the RGB methodology, we will present the most accurate results (from (2) or (3)) using the minimum as aggregation technique, with the objective of having no FP. On the other hand, regarding the edge detection, we are going to present the results using the Laplacian filter with the sum as the aggregation technique and using the threshold value obtained from Table II. A scheme of the combination of methods and techniques is presented in Figure 11. In this Figure, we can see the different steps carried out in order to obtain our results. First, the individual techniques are applied. Following, the aggregation technique is used, followed by the classification method. Finally, both images are joined.

The technique of band combinations offered the following results. The method shows that in both images, the weeds are detected with the (3). The results of this methodology are FP≈45, TP=1, FN=0. In the second image with weed presence, it was not possible to detect the weed presence clearly with any of the RGB methods. With (2) we obtained the following results: FP=5, TP=0, FN=1 and with (3) FP>100, TP=3, FN=0. With the (3) it was possible to detect the presence of weed but the number of FP is very high, and we consider that none of the equations offer appropriated results. Finally, with the images without weed presence, the results of the first and second images are FP=6 and 10 with (2) and FP≈ 100 in both cases with (3).

The results of using the edge detection method are the following ones. In the case of images with weed presence, the resultant images indicate the presence of weed in both cases the weeds are indicated TP= 1 and 3. Nonetheless, the results indicate the presence of weed in areas without a weed in one of the cases FP= 1 and 10. This method does not offer any FN. In the case of images without weed, the method offered in both image results in some FP, FP= 5 and 7 in each image. The resultant images of both filters and their combination in the images with weed presence are presented in Figure 12. First, the original images are shown and the presence of weed is indicated in red circles. Then the individual results of each technique are presented, the positive results (pixels identified as weeds) are in red. Finally, the results of combining both methodologies are presented.

We can affirm that both methods (RGB and edge detection) are promising options for weed detection in grass gardens. Nonetheless, both methods need to be improved since a considerable number of FP are given. This fact is more relevant in the case of the RGB method with (3).

Finally, we can join the data from both methods to improve the actuary. Therefore, if we combine the results of (2) and the Laplacian filter the weed detection improves considerably. The results are summarized in Table IV. The number of FP has been reduced. There is only one FP in Image 2. The importance of the FP in an image when there is a TP, as in the case of Image 2, is low. In the images without weed presence, there is no FP. On the other hand, the weeds are correctly identified in the images with the presence of weed (Image 1 and Image 2). Thus, there is no FN in each image.

VI. CONCLUSION

In this paper, we have presented our proposal for weed detection in lawns using two image processing techniques. The objective is to detect the weeds to apply the phytosanitary products only to the affected area.

We use a mathematical combination of the RGB bands and the edge detection filters to obtain new image data, which can be used to detect the weed. First, we found a formula that can be used to remove the soil from the images as pre-processing. Then, after analyzing the RGB values of the weeds and the grass, we realize that there are two big groups of weeds. The ones with a bluish coloration and the ones with a yellowish coloration, compared with the grass. Thus, we need to use two different formulas to detect the weed. Moreover, several filters for edge detection have been compared and the Laplacian filter was the one that offered better results. Then, we apply aggregation techniques to minimize the number of FP in both methods. Finally, we compare and combine both methods, and observe the improvement of results when both methods are used together.

By using the methodology described in this paper, it will be possible to detect weeds. This methodology is more effective for detecting dicotyledonous weeds, especially the ones with wide and big leaves. Nonetheless, in our results, some monocotyledonous leaves of weeds were detected.

The future work will be related to the identification of different weed species using artificial intelligence and machine learning techniques. Those techniques will be applied not in the node itself, but in a cloud server. Moreover, we will work with images taken at a higher height and evaluate the benefits of using a thermal camera in conjunction with the RGB camera. Finally, and in order to estimate the reduction in phytosanitary product use, we will implement this methodology in golf courses. In those scenarios there is a huge area covered by grass and maintaining them without weeds is a key factor for the manager.

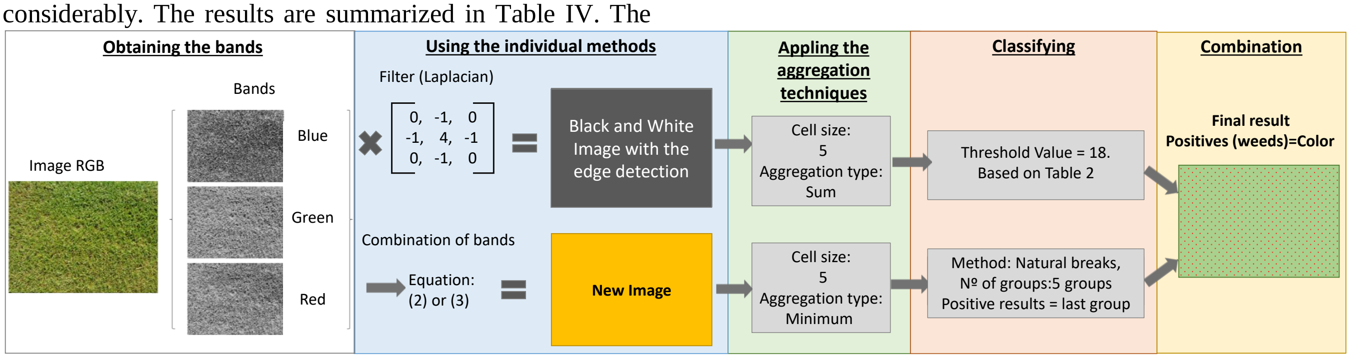


Figure 11. Block diagram of the process including the selected technics.

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TABLE IV. COMBINATION OF RESULTS

		Image			
Method	**Parameter**	**1)**	**2)**	**3)**	**4)**
Band combination using (3)	TP	1	3	0	0
	FP	≈45	>100	≈ 100	≈ 100
	FN	0	0	0	0
Edge detection Laplacian	TP	1	3	0	0
	FP	1	10	5	7
	FN	0	0	0	0
Combination	TP	1	3	0	0
	FP	0	0	0	0
	FN	0	0	0	0

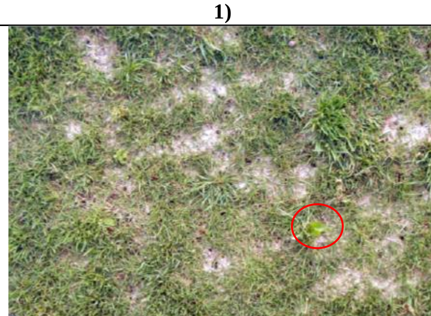
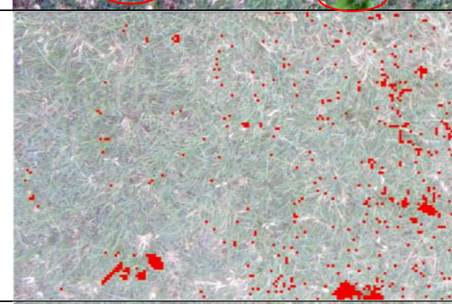
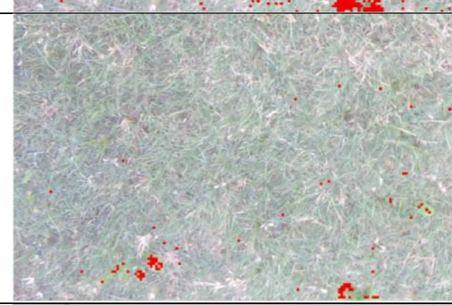
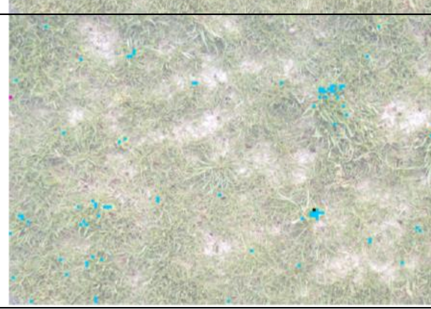
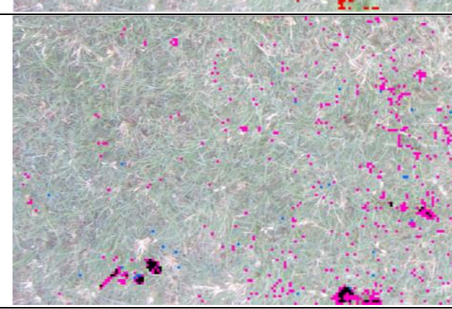
Image	**1)**	**2)**
RGB image		
Image of RGB Band Operations using (3)		
Image of Edge detection		
Resultant image of combinations: • **Blue pixels (positive results of RGB)** • **Pink pixels (positive results of edge detection)** • **Black pixels (positive results of combination)**		

Figure 12. Details of the combination of results in Figures with weed presence

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Normalizing Public Transport Accessibility Data in Real-Time

A Systematic Transformation of Accesibility Data to RDF

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***Abstract*—Smart mobility is a major component of smart city initiatives and is focused on improving citizens' mobility. One of the policies employed to increase mobility is that of promoting the use of public transport. But if this use is to be made extensive, it is necessary to make transport much more inclusive and accessible. Providing applications that guide citizens as they travel around the city on public transport is not something new, but it often occurs that these applications do not have information regarding accessibility that will allow users to establish routes according to their needs. One of the origins of this situation is that these public transport accessibility data are not easy to find or use in order to develop applications that address this issue. Moreover, in many cases the information is not updated in real time. In this work, we present a smart data framework that is capable of managing accessibility data related to public transport and gathering information about incidents in the transport network in real time. These data are annotated semantically and published as open data using automatic transformations defined with the RDF modelling language, thus making data immediately available for the calculation of new accessible routes.**

Keywords - Public transport; accessibility; linked open datasets; normalization; RML.

I. INTRODUCTION

As stated in our previous work, presented at SMART ACCESIBILITY conference, urban mobility is one of the greatest challenges for modern cities [1]. It is a complex problem in which very different aspects, such as air and noise pollution, traffic congestion or medical and economic costs resulting from accidents, have to be considered [2]. Smart mobility as part of smart cities would appear to be one of the main approaches by which to solve this problem [2].

The source of all problems in urban mobility is the flow of people and vehicles attempting to use the same spaces at the same time. One improvement that could be made is that of stressing the importance of using the public transport, which would, however, be much more efficient if people were able to avoid colliding with other people when traversing the cities. This could be done if they were able to use their own smart devices to find specific routes within the urban space.

A software system that provides maps and calculates routes in public transport networks is no longer a novelty. However, most of the current routing systems still do not consider accessibility. Even the most popular among them, Google Maps, does not provide accessible routes. However, institutions such as the European Union (EU) aim to provide initiatives that will improve the information concerning the accessibility of the urban transport network: "the special needs of user groups in different cities need to be taken into account" [3] and to provide those users with real-time information in order to improve their mobility and well-being [2].

But, why do route calculation applications not provide accessibility information? The main reason is that information of this type is scattered in different sources and formats. That is, there are no easily available data that can be used to provide accessible routes to users with special needs.

The intention of our previous research has been to use semantic information to fill this niche [1][4][5][6][7]. In [7], we worked with the Public Bus network of the city of Madrid. In our other work, we have gathered the data concerning the metro infrastructure in the city of Madrid (Spain) and the accessibility features of that infrastructure, which we have then used to develop an open data semantic repository [4][5]. These data are, therefore, now available for the applications that provide accessible routes.

Building upon this infrastructure, our platform is able to evolve beyond its original constraints, and thus consider higher accessibility levels. Our initial architecture had to deal with mostly non-volatile data, i.e., data with a small rate of change. When our system has to compute a route, it usually uses very stable data (the structure of the network, predefined timetables), and their alterations usually have a certain durability (planned work, changes in the infrastructure or the rolling stock). However, other sources of change are much less predictable: collapses, floods, accidents, or even the traffic flow. These are usually easy to perceive once they have occurred - but many citizens are unaware of these *incidents* until they encounter them.

Our system must, therefore, include incident management to be complete. This would allow our smart data to include live information and to provide an even more intelligent response in real-time, which would take the situation at any given moment into account. This is particularly important when considering accessibility and the relevant groups of interest. Owing to the need for real-time data, in [1] we, therefore, collected data provided by Metro Madrid users and related to incidents regarding accessibility elements, such as lifts, stairs, etc. This data collection is carried out using a *crowdsourcing* strategy: it is the users themselves who provide information about incidents at the moment at which they encounter them. This information is sent using mobile devices is stored in our routing platform, and has probably been attained from many coincidental sources. These new data are collapsed and integrated with pre-existing accessibility information – signifying that semantic annotations are also used for their processing when an accessible route is calculated. In summary, their combination can be conceived as *real-time accessibility data*. This approach effectively provides an advantage over other approaches, such as those discussed in the Related Work Section.

This integration of data from *crowdsourcing* into the aforementioned semantic repository (data concerning infrastructures and accessibility features) implies several challenges: their specific meanings and vocabulary; the incident lifecycle management, or the handling of simultaneous sources, and even their scale. Our evolved architecture must deal with all of this, and this paper presents our solution.

One of these challenges, i.e., the handling of simultaneous sources and different formats, can be addressed by means of a mapping language: mapping rules are defined to convert the collected data (in this case, in a JSON file) into an RDF model. The use of the mapping language facilitates and speeds up the task of transforming and linking data.

With regard to the date scale, the use of a mapping language also facilitates this task, especially if the data set is very large, as an automatic transformation is performed by applying the rules defined.

The paper is structured as follows: Section II presents some related works, and Section III describes our CoMobility and Access@City projects, which constitute the context of this work. Section IV presents the smart data framework developed, describing our proposed client-server scaling architecture and the main semantic technologies used to model the semantic repository. Section V describes the semantic vocabulary employed to annotate events and the set of mapping rules that converts the incident data into RDF triples using that vocabulary. Section VI describes how we validated this set of rules by means of a case study with the MM4A4 App [1], and our conclusions and future works are presented in Section VII.

II. Related Work

There already are several software applications that provide information about specific aspects of the public transport domain. In some cases, they include accessible wayfinding information or/and accessibility features, or elements for people with special needs or disabilities. Other software provides data about public transport using a crowdsourcing approach. In this section, we discuss some of the most representative of them.

Of those related to accessibility, we should mention Landmark Ontology for Hiking [8], which is focused on elderly people and helps them to walk less by using wheelchairs. It formally represents landmarks for hiking. Wheelmate [9] and/or Wheel Map [10], meanwhile, provide some information about accessible places for people in wheelchairs, and Access Map provides accessible routes to people with mobility needs [11]. All of these consider only mobility-related disabilities. Furthermore, "Ciudades Patrimonio de la Humanidad" has a web application that provides accessible routes to people with special mobility needs, including blind or hearing-impaired people [12]. However, none of these applications are customizable.

The EU is making a great effort to improve public transport [3]. Projects like ACCESS 2 ALL [13] or Mediate [14] have been set up with the objective of analysing how to answer all citizens' accessibility needs. The goal of ACCESS 2 ALL is to define mobility schemes and guidelines in order to ensure the accessibility of public transport to all citizens, such as the elderly and the disabled. It, therefore, began by defining user needs. Moreover, it proposes customised services for route guidance coupled with localisation methods. Furthermore, the Mediate Project has identified a set of indicators with which to describe accessibility, has developed a tool to measure the accessibility of urban transport and has published a Good Practice Guide for accessibility. These projects seek to establish a theoretical framework covering all aspects of citizens' mobility, but do not offer solutions in the form of user applications.

Of those that employ a crowdsourcing approach, some applications use crowdsourcing to improve the experience of using public transport and to provide real-time information about the status of public transport. For example, Tiramisu Transit provides data such as how full a bus is or whether any wheelchair space is left [15]. Moovit is able to plan routes and indicate when to get off, or the status of the service [16]. Swiftly works with transport agencies rather than with the general public [17]. It provides more accurate vehicle arrival data for these transport agencies, thus enabling them to provide their users with better information. The OneBusAway project consists of a set of tools to improve the user experience on public transport by ensuring that buses and other transit systems arrive on time, decreasing waiting times, increasing feelings of safety, or even increasing transit trips per week [18]. OneBusAway provides several feedback mechanisms that allow users to make comments about these tools.

Other initiatives that use crowdsourcing are the BUSUP project [19] and the CIVITAS initiative [20]. The former allows users to book crowdsourced buses on demand, while the intention of the latter is to achieve cleaner, better transport in Europe. A CIVITAS subproject is dedicated to mobility strategies for vulnerable groups.

OpenTripPlanner (OTP) is another project with which to provide services for passenger information and transport network analysis [21]. It computes routes by combining transit, pedestrian, bicycle and car segments traversing networks built from OpenStreetMap [22] and GTFS [23] data. OTP also takes (transport) accessibility into account.

As will be noted, the number of systems whose purpose is to improve the user experience in the public transport are increasing. However, most of them (with some exceptions, such as Tiramisu Transit or CIVITAS) do not take the information about accessibility elements into account, despite the fact that these elements are necessary for users with special needs in order to also improve their experience on public transport. Even the aforementioned systems [15][19], although they provide accessibility features, do not allow the users to inform about the actual state of these elements: whether a lift is operative, if work is taking place that will prevent or hinder access for, i.e., blind people, etc.

To the best of our knowledge, there are currently no software applications that analyse the status of the public transport network in order to estimate the availability of accessibility features, while also using crowdsourcing to update their data.

With regard to the transformation of the collected data (in a certain format) into RDF for publication in a semantic repository, several works propose the automatic execution of mappings. Most existing solutions are based on a specific format [24]: for example, R2RML converts data from relational databases [25]. There are several approaches with which to convert data from csv and spreadsheets into the RDF data model, which are based on the idea that each row describes a resource and each column represents a property [24]. Some examples are the XLWrap's mapping language [26] or Tarql [27], both of which convert CSV into RDF using SPARQL. There are a variety of solutions with which to map from XML to RDF that rely on XSLT, XPATH or XQUERY [24]. Few tools support mappings from different source formats to RDF. Furthermore, those tools cannot integrate data from different sources. OpenRefine [28] and Virtuoso Sponger [29] are examples of this type of tools.

III. THE CONTEXT: COMOBILITY AND ACCESS@CITY PROJECTS

This work is being developed in the context of two research projects. The first, called CoMobility [30], defines a multimodal architecture based on linked open data for sustainable mobility. Its main goals are to improve citizens' mobility and to optimize their trips by combining public transport and car sharing. The second, called Access@City, is a coordinated project that defines a technological framework in which to process, manage and use open data concerning public transport with the goal of promoting its accessibility [31]. One of its subprojects is Multiply@City, which focuses on processing and harmonizing public transport accessibility data in a semantic manner by means of an ontology, taking into account that data are provided by different sources and have different formats [32]. The accessibility data are obtained from open data by means of Web scraping and they can also be updated here via crowdsourcing techniques. Fig. 1 provides a general depiction of the latter project.

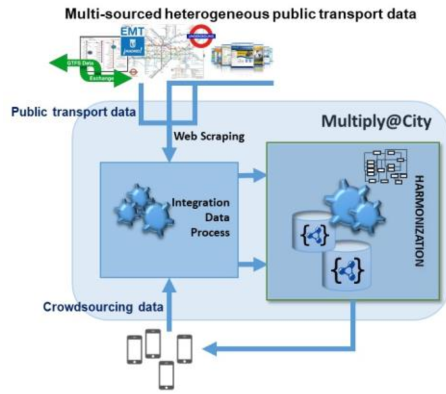


Figure 1. Multiply@City project architecture.

The Regional Consortium for Public Transport in Madrid (CRTM) [33], the Madrid public bus company (EMT Madrid) [34], and the Spanish National Society for the Blind (ONCE) [35] have all expressed their interest in the results of our CoMobility and Access@City projects.

IV. BACKGROUND

In this section, we introduce our smart data framework, which is based on the Resource Description Framework (RDF) and the RDF Mapping language (RML) semantic technologies. The framework describes the architecture that supports our work. The semantic technologies will be used in order to define our current proposal.

A. *The Smart Data Framework*

Our Smart Data Framework (SDF) was defined in full in Cáceres et al. [1]. In this subsection, we introduce the most relevant aspects.

The SDF is supported by a client-server architecture (see Fig. 3), which allows communication between different Android apps and a server. The app related to this work, denominated as MMA4A, provides two different alternatives to users: (a) requesting an accessible route by considering their specific needs as regards getting around using the Metro, and (b) collecting events or incidents related to unavailable accessibility features (lifts, escalator, stairs, etc).

In order to compute the route (a), it is first necessary to obtain the infrastructure data concerning the public transport network, and to request the current state of that infrastructure – provided by the server. It is then necessary to establish a correspondence between the accessibility elements (their current state) and the user's needs. Transmodel [36] and IFOPT [37] standards have been analysed in order to identify the specific accessibility characteristics that each special need requires. TABLE I summarizes the accessibility elements and their correspondence with the users' needs considered in this work.

Both models (IFOPT and Transmodel) have been used as a basis on which to develop a specific *vocabulary* as an RDF Schema [38], which comprises the information required to semantically annotate the events regarding accessibility that can be produced, which are obtained via crowdsourcing. Fig. 2 shows the RDF Schema employed to describe this terminology and its relationships. This schema includes terms with which to describe the incidents.

In order to annotate the events regarding the accessibility elements with the concepts defined in the RDF Schema shown in Fig. 2, it was necessary to define a vocabulary denominated as MAnto. TABLE II provides a summary of the MAnto vocabulary.

The use of this vocabulary makes it possible to register an incident, e.g., a lift does not work (*hasLift FALSE*) at a specific *StopPlace* (i.e., station) on a specific *ofLine* (transport line). This event also has an associated opening date (*openDate*). When the incident is solved, we can close it by indicating the final date (*closeDate*) and then assigning a TRUE value to both *hasLift* (the original feature) and *closedEvent*.

The event data concerning accessibility features, which is processed from many sources (*crowd*), is semantically annotated on the basis of this vocabulary and is then stored in the semantic repository, in the events collection.

Once the events have been collected by the users (b), it is also necessary to send these incidents to the server (as a JSON file), in order to update the current accessibility features in the network. It is, therefore, necessary to develop a specific server architecture that stores the infrastructure data and its accessibility status and is updated using the crowdsourcing approach.

TABLE I RELATIONSHIP BETWEEN FEATURES AND USERS' NEEDS

Accessibility features of public transport (based on IFOPT)	Users' accessibility needs (based on IFOPT)			
	Auditory and visual	Mobility	Phobia to lifts	Phobia to escalators
Lift	✓	✓	×	✓
Escalator	✓	×	✓	×
Ramp	✓	✓	✓	✓
Stairs	✓	×	✓	✓
Travelator	-	-	✓	×

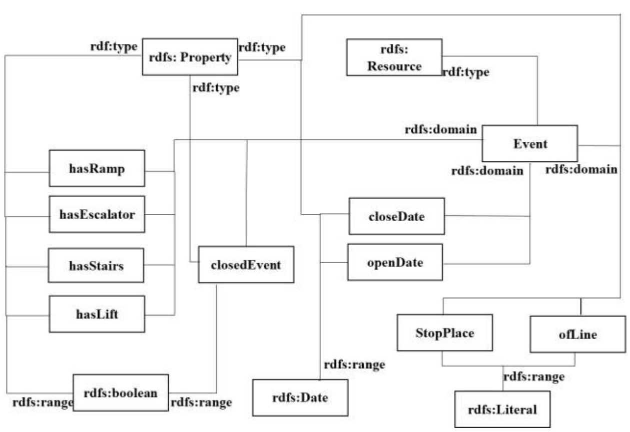


Figure 2. Events vocabulary in RDF Schema.

In the server, which is denominated as Coruscant, we have implemented Spring Boot [39] as the application server (AppServer), an Apache Kakfa [40] server and an Apache Jena Semantic Repository (SR) [41]. The server should simultaneously 'listen to' the (potentially many) notifications of incidents or events concerning the accessibility features that are not available in the public transport network at that moment. It is for this reason that we have implemented the Apache Kakfa server as a Queuing Manager (QM). The QM gathers the different events that users have notified by employing their smart devices, i.e., the QM gathers the JSON files generated by the apps. The JSON files are transformed into RDF data by the AppServer and the RDF data are then stored in the SR.

The SR maintains two separate data collections: one of them provides the (mostly static) data concerning stations, lines and stops, denominated as the *infrastructure collection*, and the other provides the (dynamic) data concerning the state of the network as regards its accessibility features, denominated as the *events collection*.

TABLE II EVENTS MANTO VOCABULARY

MAnto term	Description
`mao:event`	Opens an event
`mao:closedEvent`	Closes the event
`mao:openDate`	Registers the date of the incident
`mao:closeDate`	Registers the closing date of the incident
`mao:hasLift`	Registers whether the lift works
`mao:hasStairs`	Registers whether the stairs are accessible
`mao:hasEscalator`	Registers whether the escalator works
`mao:hasRamp`	Registers whether the stairs have a ramp
`mao:hasTravelator`	Registers whether the travelator works
`mao:StopPlace`	Assigns the incident to a station
`mao:ofLine`	Assigns the incident to a transport line

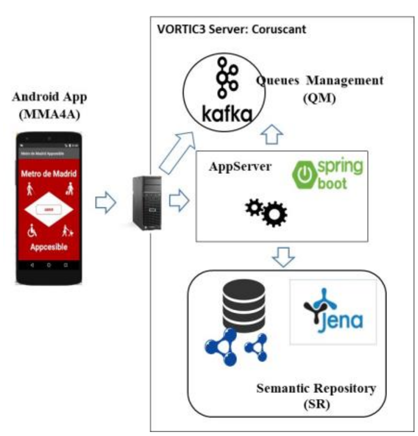


Figure 3. Architecture framework.

B. *The Resource Description Framework (RDF)*

The Resource Description Framework (RDF) provides a very simple model for data interchange on the Web [42]. In RDF, the data that are distributed by the Web (also called resources) are described as a set of triples. A triple is formed of three components: a subject, a predicate and an object. The subject is a resource that is related to an object by means a predicate. The object can be another resource, which has been defined previously, or a literal. The predicate can describe a relationship between the subject and object or a property of the subject [43].

In order for the data of which the triples are formed to be referenced, RDF identifies each component of the triple with a URI (Uniform Resource Identifier) [44]. For example, a car with a set of features (make: BMW, license plate: "5644BHZ" and colour: red) is modelled in RDF as Fig. 4 shows.

The URI "http://www.vortic3.com/5644BHZ" would identify a car with the license plate number "5644BHZ" that has been manufactured by BMW and is red.

The set of triples can be represented graphically as a directed labelled graph (RDF Graph) on which subjects and objects are nodes and predicates and are represented with edges. The triples of the previous example form the graph shown in Fig. 5. The edge labels preserve the semantics of the relationship, signifying that the use of standard vocabularies that can always be interpreted in the same way by those who use the data is highly recommended. Sometimes, depending on the data domain, no vocabulary has been defined and it is necessary to formalize a new one. In Fig. 5, the label "http://purl.org/vso/ns#color" would identify where the semantics of that predicate is formalized, thus allowing all the users of that data to interpret the predicate in the same way. This condition facilitates the integration of several datasets by merging several RDF graphs. The integration takes place at the most basic level of triples, that is, connecting two datasets can be as easy as establishing a predicate between resources from different datasets or determining a common resource between those datasets.

Number	Subject	Predicate	Object
1	http://www.vortic3.com/5644BHZ	http://purl.org/goodrelations/v1#hasManufacturer	"BMW"
2	http://www.vortic3.com/5644BHZ	http://purl.org/vso/ns#color	"Red"

Figure 4. RDF Triples.

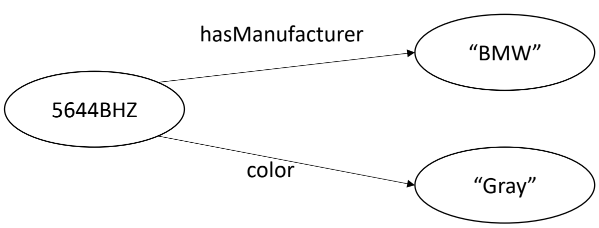


Figure 5. RDF Graph.

The representation as a graph allows a better understanding of the relationships among data. This representation must be transformed such that computers can handle the data. One of the most frequently used notations is RDF-XML [45]. Fig. 6 shows the serialization in RDF-XML notation for the graph in Fig. 5.

Data can be extracted from this RDF file by means of SPARQL queries [46] or by parsing the XML file.

In summary, by using RDF to model Web data it is possible: a) to integrate data from different sources; b) to publish data in order to reuse and share; c) to modify or increase data without affecting the customers who use them; and d) for computers to interpret the information modelled with RDF using a standard model that preserves its meaning.

C. *The RDF Mapping language (RML)*

RML (the RDF Mapping language) is a general language that permits the definition of rules with which to map heterogeneous data sources onto RDF graphs [24].

The transformation from each data source into RDF is usually carried out independently, after which data from different sources are interlinked. This causes the previous definitions to be disregarded or the same concepts to appear in different datasets and even with different names. In order to avoid this problem, the data must be incorporated and interlinked with the published data at the same time as they are converted to RDF triples. RML solves this problem by converting the data to RDF at the same time as it interlinks them with existing datasets.

RML is an extension of R2RML. R2RML permits express rules to transform data in a relational database into an RDF graph [25], while RML makes it possible to define rules that map relational and semi-structured data (e.g., XML, JSON…) onto RDF graphs. Fig. 7 shows the RML structure.

In RML, the data source is defined with a Triples Map rule that consists of a Logical Source, a Subject Map and zero or more Predicate-Object Maps [47]:

```
<?xml version="1.0"?>
<rdf:RDF
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-
syntax-ns#"
  xmlns:vso="http://purl.org/vso/ns#"
  xmlns:gr="http://purl.org/goodrelations/v1#"
  xmlns:dc="http://purl.org/dc/elements/1.1/">
  <rdf:Description
rdf:about="http://www.vortic3.com/5644BHZ">
   <gr:hasManufacturer>BMW</gr:hasManufacturer>
   <vso:color>Red</vso:color>
  </rdf:Description>
</rdf:RDF>
```

Figure 6. RDF Graph in RDF-XML notation.

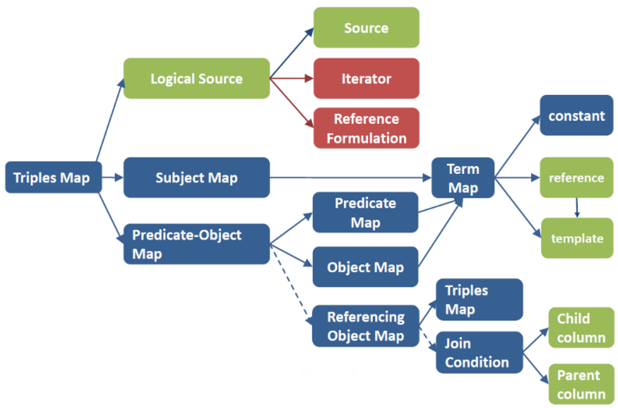


Figure 7. RML structure (from http://rml.io/RMLmappingLanguage.html).

- The Logical Source establishes the data source and where it is (Source). The source can be a relational database, JSON or XML documents, etc. Data from that source are accessed by defining an iterator pattern (Iterator) on the input data. The iterator pattern describes how the input data should be retrieved. For example, if the data source is an XML document, an XPath expression can be used to define how to extract the data. If the input data are contained in a JSON document, a JSONPath expression can define the iterator on data, and an SQL query can define the iterator on a relational database. The type of expression that defines the iterator is specified in the Reference Formulation. RML has the following predefined Reference Formulations: XPath, JSONPath, SQL2008, CSV, CSS3 and JSONPath (see http://rml.io/RMLmappingLanguage.html).
- The Subject Map defines the rule required to generate the URIs that identify the resources to be mapped and is used as the subject of all the triples that this Triples Map rule generates.
- Finally, the Predicate-Object Map rules define how triples are formed. These rules have two elements: The Predicate Map, which specifies how the predicate is defined, and the Object Map, which determines how the object is generated.

The Subject Map, the Predicate Map and the Object Map are Term Maps, that is, rules that produce an IRI, a blank node or a literal. A Term Map can be mapped onto a constant value, a data value of a referenced data fragment in a given Logical Source, or a template that is a valid string template, which can contain the referenced data fragments of a given Logical Source [47].

In order to transform a complete data source, we can define as many Triple Map rules as we need.

RML solves the above mentioned problem of generating the triples and then linking the data. The solution is attained by specifying resources as URIs when the Subject Map and the Object Map are defined. When data are incorporated into a dataset, the same schemes are, therefore, used to define the resources that are linked at the same time as the triples are created [24].

V. NORMALIZING SMART ACCESSIBILITY DATA

As mentioned in the Background Section, the MMA4A app stores the users' notifications regarding the state of accessibility features of the Metro in real-time as JSON files and then sends them to the Coruscant server. Once in the server, the QM gathers the different JSON files generated by different users, after which the AppServer transforms the JSON files into RDF data and then stores these data in the SR. At this point, we wish to underline that this transformation from JSON files to RDF data was carried out by means of a custom-made Java code specifically developed for that purpose.

This work focuses on the transformation of the JSON files, which are the events or incidents generated by the MMA4A users in real-time, into RDF data using RML. As mentioned previously, RML is a generic mapping language that can express rules that map data with heterogeneous structures and serializations onto RDF graphs. The "RML in details" web page (http://rml.io/RML_details.html) states that most current methods support only mappings from a certain source format, employing source-centric approaches for each of the formats they support. It also states that RML supports the definition of the mapping rules independently of the references to the input data. In this respect, the reusable mapping definition RML allows the same mapping rules to be reused across different sources as long as they capture the same context only by adjusting the reference to the input source that contains the relevant information.

We, therefore, now propose to normalize the mapping rules from JSON files into RDF data by means of RML, which benefits the software maintenance of our smart accessibility data and thus avoids the need to use the custom-made Java code.

The RML mapping rules that automatically transform data in JSON format into RDF are presented in the following subsections.

A. *Defining RML mappings for smart accessibility data*

In this work, we propose the normalization of mappings of the smart accessibility data so as to transform them from JSON format into RDF data by means of RML. RML defines the data based on one or more *Triple Maps*, which specify how the triples will be generated from the source.

Following the structure presented in Fig. 7, we first have to indicate what the *logical source* is. In our case, the source is the JSON file ("events.json") generated by MMA4A, the *iterator* is "$" and the *reference formulation* is ql:JSONPath:

```
rml:logicalSource [
  rml:source "events.json";
  rml:referenceFormulation ql:JSONPath;
  rml:iterator "$"
];
```

We then have to indicate which the *Subject Map* is. In our case, the template is a string, which concatenates a base URL and the JSON branch ("$.station"), and the class indicates an event (mao:event):

```
rr:subjectMap [
  rr:template
     "http://manto.vortic3.com#{$.station}";
  rr:class mao:event
];
```

Finally, we have to indicate which the *Predicate-Object Maps* are. There are four mandatory predicate-object maps:

(i) The date on which the incident opened, with the open date as the *Predicate* and the date value as the *Object Map*:

```
rr:predicateObjectMap [
  rr:predicate mao:openDate;
  rr:objectMap [
    rml:reference "openDate"
  ]
];
```

(ii) The line on which the incident has occurred, with ofLine as the *Predicate* and the line value as the *Object Map*:

```
rr:predicateObjectMap [
  rr:predicate mao:ofLine;
  rr:objectMap [
    rml:reference "line"
  ]
];
```

(iii) The station at which the incident has taken place, with sch:name as the *Predicate* (from the sch vocabulary) and the station value as the *Object Map*:

```
rr:predicateObjectMap [
  rr:predicate sch:name;
  rr:objectMap [
    rml:reference "$.station"
  ]
];
```

(iv) One or more accessibility elements, indicating whether or not they work: for example, hasLift as the *Predicate* and hasLift value as the *Object Map*:

```
rr:predicateObjectMap [
  rr:predicate mao:hasLift;
  rr:objectMap [
    rml:reference "$.hasLift"
  ]
];
```

B. *Developing RML mappings*

The designated software presented in this work, is related to the AppServer (which is located in the Coruscant server and is supported by Spring Boot technology), as shown in Fig. 1.

As mentioned previously, we have already developed a custom-made Java code, which transforms the JSON java file generated by the MMA4A app into RDF format. We have now implemented a set of mappings by means of RML in order to transform the JSON file into RDF. The top-level design is shown in Fig. 8.

Before implementing the final solution, we have designed an AppServer package, which is structured in different classes and supports the full functionality of the AppServer. Fig. 9 shows this design by means of UML.

The AppServer software has three actors: the MMA4A Android app, which serves the JSON events file; the QM, which gathers the different real-time event files; and the Semantic Repository, which stores the RDF data generated. Moreover, we consider that the AppServer is a UML package, which is composed of a set of UML classes and their relationships: an MMA4A interface, which receives each JSON events file from the App and serves it to the ServerManager class; a QM interface, which serves the JSON event file from the ServerManager class to the QM actor in order to be consumed by it, and later receives the corresponding event file to be consumed, after which the ServerManager orders to transform the JSON events file into RDF data on the SR interface. In particular, the *addEventsintoGraph* method of the *SRInterface* class receives the JSON file as a parameter and then generates the events RDF graph by means of the RML mappings.

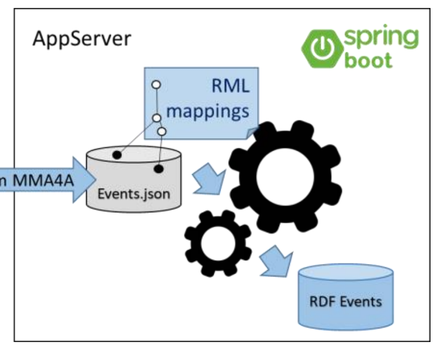


Figure 8. Top-level software design.

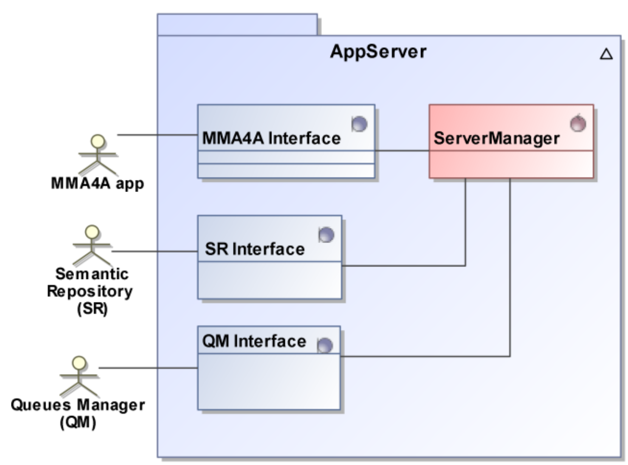


Figure 9. The AppServer package.

TABLE III shows an example of the RML mappings code with which convert the JSON event file into an RDF graph.

VI. VALIDATION

In this section, we validate our proposal for the normalisation of smart accessibility public transport data by means of RML.

This validation is performed using the MM4A4 App [1]. This App is aimed at users of the Metro of Madrid who can warn when they find an incident in the accessibility elements of the network. By using this App, we have defined the following process for this purpose:

- First step. A user X, who has a specific user need, employs MMA4A to request a route. This route is composed of stations at which each of the accessibility features works correctly.
- Second step. A user Y notifies an event by means of MMA4A, which indicates which accessibility feature does not work at a specific station.
- Third step. The App sends the JSON event file to the Coruscant server, and the SR Interface class then generates the RDF file by means of RML mappings. This RDF file can be downloaded from http://coruscant.my.to:8080/download/events.xml.
- Fourth step (*). We now validate the current RDF file by means of the RDF validator (https://www.w3.org/RDF/Validator/) in order to verify its correctness.
- Fifth step (**). User X again requests the same route as in the first step. We should stress that this route is composed of stations at which some accessibility features do not work, including one related to the previously notified event. We verify whether or not the user obtains an accessible route.

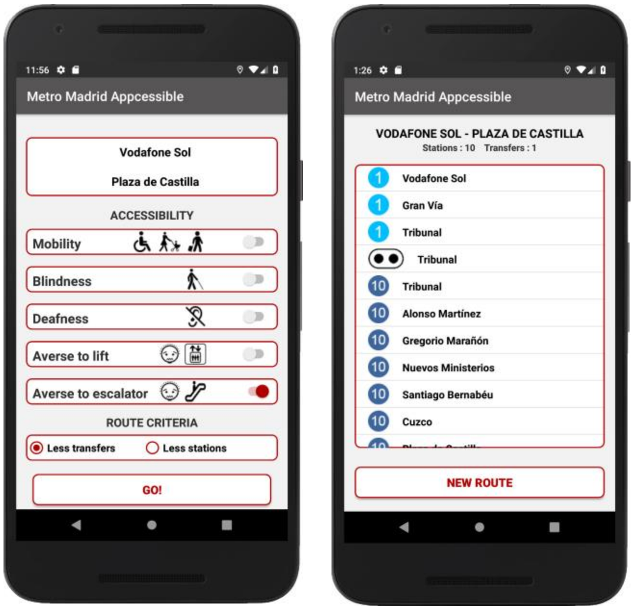
This process includes a double validation. The first (*) is the checking of the correctness by means of the RDF validator, as mentioned in the fourth step. The second (**) concerns the correctness of the route calculated by MM4A4, as mentioned in the fifth step.

Details of this process for a specific example are shown as follows.

First step: A user (User X) requests a route starting at the Vodafone Sol station and finishing at Plaza de Castilla station, considering a phobia as regards escalators (the user interface is shown in Fig. 10a). In this case, a route exists and requires a transfer at Tribunal station. The complete route is: from Vodafone Sol station, take Line 1 (cyan blue) of the Metro to Tribunal station, then transfer to Line 10 (dark blue) and go to Plaza de Castilla. The details of this route are shown in Fig.10b.

TABLE III SPECIFIC RML MAPPINGS FROM OUR JSON DATA.

```
@prefix rr: <http://www.w3.org/ns/r2rml#>.
@prefix rml: <http://semweb.mmlab.be/ns/rml#>.
@prefix ql: <http://semweb.mmlab.be/ns/ql#>.
@prefix mao: <http://manto.vortic3.com#>.
@prefix sch: <http://schema.org/>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.

<#JSONEvents>
  rml:logicalSource [
    rml:source "event.json";
    rml:referenceFormulation ql:JSONPath;
    rml:iterator "$"
  ];

  rr:subjectMap [
    rr:template
"http://manto.vortic3.com#{$.station}";
    rr:class mao:event
  ];

  rr:predicateObjectMap [
    rr:predicate mao:openDate;
    rr:objectMap [
      rml:reference "$.openDate"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:closedEvent;
    rr:objectMap [
      rml:reference "$.closedEvent"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:closeDate;
    rr:objectMap [
      rml:reference "$.closeDate"
    ]
  ];

 rr:predicateObjectMap [
    rr:predicate mao:ofLine;
    rr:objectMap [
      rml:reference "$.line"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate sch:name;
    rr:objectMap [
      rml:reference "$.station"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:hasLift;
    rr:objectMap [
      rml:reference "$.hasLift"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:hasEscalator;
    rr:objectMap [
      rml:reference "$.hasEscalator"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:hasStairs;
    rr:objectMap [
      rml:reference "$.hasStairs"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:hasTravelator;
    rr:objectMap [
      rml:reference "$.hasTravelator"
    ]
  ];

  rr:predicateObjectMap [
    rr:predicate mao:hasRamp;
    rr:objectMap [
      rml:reference "$.hasRamp"
    ]
  ].
```



(a) Request a route (b) The calculated route

Figure 10. User interface of MM4A4.

Second step: A user (User Y) notifies two events (the lift and stair accessibility features do not work) at Plaza de Castilla station.

Third step: The JSON event file sent to the Coruscant server and the RDF file is generated by means of RML mappings. TABLE IV shows the partial code (the stair accessibility feature does not work): the first row shows the JSON file of this event and the second row shows the corresponding RDF graph. We then download the RDF event file and, in the next step, we verify this RDF code.

Fourth step: The validator successfully checks the RDF file. Fig. 11 shows a partial screen capture.

Fifth step: User X again requests the same route as in the first step (from Vodafone Sol to Plaza de Castilla station and considering a phobia as regards escalators); we should highlight that the previous route generated for user X is now composed of stations at which some accessibility features do not work, which are those related to the event previously notified by user Y. We must, therefore, verify whether or not user X can obtain an accessible route.

It is important to stress that our algorithm provides a route only after examining whether the start (in this case, Vodafone Sol station), destination (Plaza de Castilla station) and any transfer stations (the previous transfer station was Tribunal) have the required accessibility features. In our case study, we have requested a route starting at the Vodafone Sol station and ending at the Plaza Castilla station. Then, as previously indicated, user Y notifies events at Plaza de Castilla station and the app now notifies user X of their existence (see Fig. 12a and b).

TABLE IV EVENTS: JSON AND RDF FORMAT

```
{"station":"Plaza de Castilla",
 "line":10, "hasStairs":false,
 "openDate":" 2019-06-11T09:50:33.960",
 "closedEvent":false}
```

```
<http://manto.vortic3.com#Plaza%20de%20Castilla> a
  <http://manto.vortic3.com#event> ;
    <http://schema.org/name> "Plaza de Castilla" ;
    <http://manto.vortic3.com#openDate> "2019-06-
11T09:50:33.960" ;
    <http://manto.vortic3.com#ofLine> "10" ;
    <http://manto.vortic3.com#hasStairs> "false" ;
    <http://manto.vortic3.com#closeDate> "false" .
```

Then, the App offers an alternative route (Line 2 - red, and Line 9 - violet) including the closest accessible station (in our case study, the closest accessible station is Ventilla, also shown in Fig. 12b).

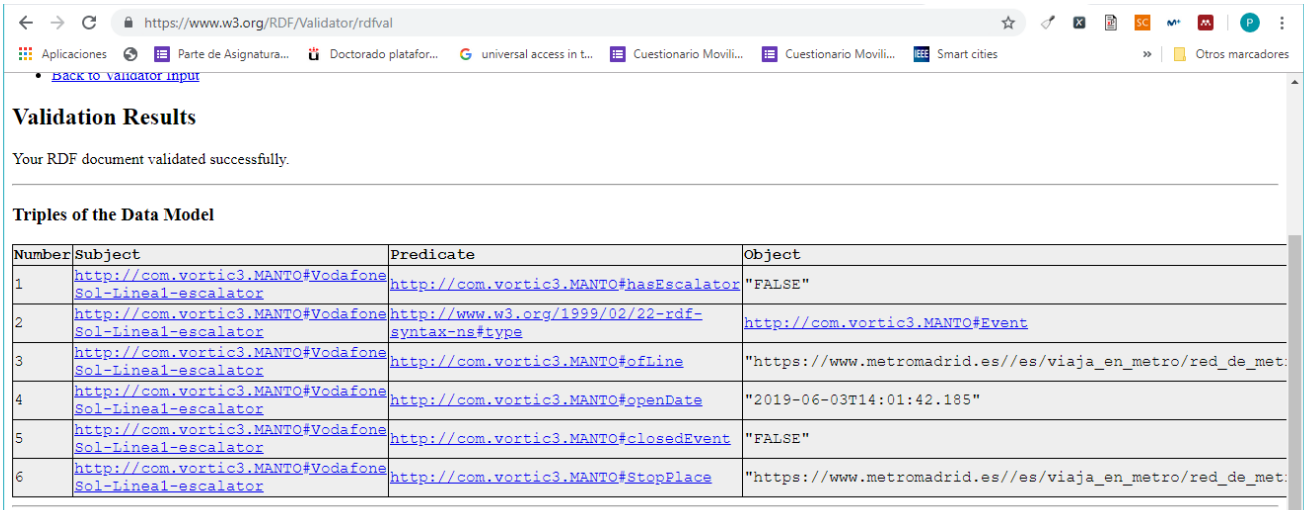
We have carried out many other tests according to the different user needs identified in this solution (auditory, visual and mobility disability, phobia to lifts and phobia to escalators). We have also verified that the routes provided by MMA4A are correct for these kinds of users.

In summary, our experience with the normalization process of smart accessibility data guarantees that the events dataset is correct and can be used to generate the routes for users with special needs, while the incidents are registered and considered while creating those routes. The validation experiment described here shows that the behaviour of the system is correct at this moment. Nonetheless, as in our previous work [1], we cannot guarantee that event notifications from the users will always be true.

VII. CONCLUSION AND FUTURE WORK

One of the major challenges of smart city initiatives is to achieve an inclusive society for all citizens, including those with special needs. One of the pillars for that inclusion is urban mobility. Our work is focused on public transport as a part of that mobility. In order to address this challenge, more thorough information about the means of transport and their accessibility features is required, thus making it possible to arrange and provide accessible routes for everybody, including those with special needs

Several web applications and tools that provide information and services for transport users already exist. We have studied some of them and, to the best of our knowledge, no software application currently takes the state of the public transport network with respect to its accessibility features at a particular moment fully into account. This is particularly the case as regards the existence of an application that updates data with a crowdsourcing strategy in order to compute accessible routes for special needs users.


https://www.w3.org/RDF/Validator/rdfval

Back to Validator Input

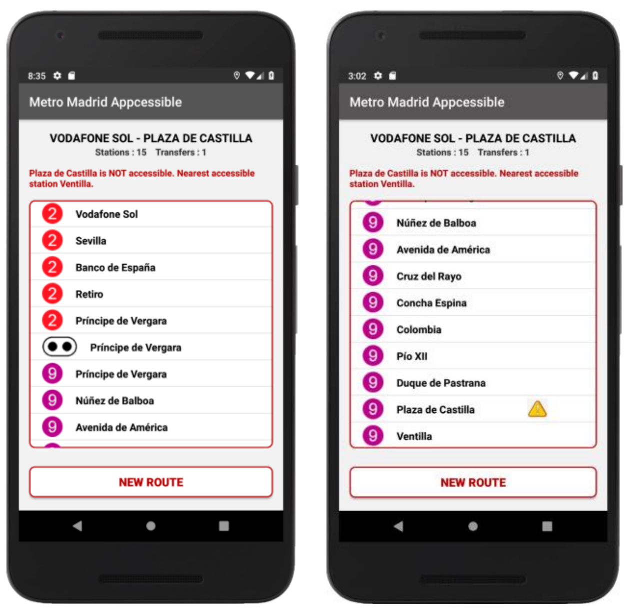
Validation Results

Your RDF document validated successfully.

Triples of the Data Model

Number	Subject	Predicate	Object
1	http://com.vortic3.MANTO#Vodafone Sol-Linea1-escalator	http://com.vortic3.MANTO#hasEscalator	"FALSE"
2	http://com.vortic3.MANTO#Vodafone Sol-Linea1-escalator	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://com.vortic3.MANTO#Event
3	http://com.vortic3.MANTO#Vodafone Sol-Linea1-escalator	http://com.vortic3.MANTO#ofLine	"https://www.metromadrid.es//es/viaja_en_metro/red_de_met:
4	http://com.vortic3.MANTO#Vodafone Sol-Linea1-escalator	http://com.vortic3.MANTO#openDate	"2019-06-03T14:01:42.185"
5	http://com.vortic3.MANTO#Vodafone Sol-Linea1-escalator	http://com.vortic3.MANTO#closedEvent	"FALSE"
6	http://com.vortic3.MANTO#Vodafone Sol-Linea1-escalator	http://com.vortic3.MANTO#StopPlace	"https://www.metromadrid.es//es/viaja_en_metro/red_de_met:

Figure 11. Partial RDF Validator screen.



(a) The calculated route: from Vodafone Sol station

(b) To Ventilla station (the closest station to Plaza de Castilla)

Figure 12. User interface of MM4A4.

In order to deal with this issue, we have proposed a *smart data architecture* to manage both the data sources related to the public transport infrastructure.

Our proposal considers accessibility features when it computes a route. But it goes beyond that, by taking real-time information into account, such as incidents that may occur at any time. Our dataset, therefore, provides a smarter response in real time. These real-time data, which originate from crowdsourcing, are collapsed and integrated with existing accessibility information, thus providing a *real-time accessibility dataset.*

We provide a Kafka Queuing Manager, which is used to gather users' notifications about the state of accessibility features on public transport, and a Jena Semantic Repository to store both these data and the infrastructure data concerning the transport network. However, in order to save the data regarding notifications in this repository, it is necessary to convert them into RDF. Each time a notification is produced, data have to be transformed in real time. This work presents a smart data framework that is able to manage public transport accessibility data and to gather information in real time about incidents in the transport network. These data are annotated semantically and published as open data using automatic transformations defined with RML. This makes it possible to ensure that data are immediately available for the calculation of new accessible routes. Furthermore, the use of this language provides the possibility of integrating new data into existing datasets.

We have also developed a smart app (still a prototype) for public transport users, which is able to compute accessible routes by taking the user's needs into account, and also provide notifications of incidents or events as regards the accessibility features in the network. In order to semantically annotate the data before storing them, we have also defined a specific vocabulary as a domain-specific RDF Schema.

With regard to future work in this area, we intend to improve the MMA4A app by introducing some characteristics of the behaviour change support systems. These kinds of systems take persuasive techniques into account with the aim of engaging and retaining the app users [47][49]. In our case, retaining the app user could imply many advantages for people with special needs, because the app user will update a lot of public transport and accessibility information. Moreover, we intend to include more public transport information from other sources and means of transport, and to integrate them into the current architecture. It will, therefore, be necessary to semantically harmonize them using our MAnto ontology, which has already been used to semantically annotate the data stored in the infrastructure collection of our Jena repository. This will make it possible to provide fully open datasets for different public transport networks. Moreover, these datasets must be published on an open platform, thus providing free access to accessibility and special needs data. In this respect, the use of RML to define the transformation into RDF is very useful as regards integrating different datasets.

In order to guarantee that the information from the crowdsourcing is truthful, we want to incorporate a user registration system and a supervision module that determines the importance of the incidence to be incorporated into the system.

We have also worked on gathering information about accessible pedestrian routes in the city, obtained via crowdsourcing techniques, capturing the geographical information and accessibility features on these routes. This information will also be incorporated as smart data into the Multiply@City platform.

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Notational Characteristics of Visual Notations Used in Decision Management

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Abstract— **The visual representation of Information System (IS) artefacts is an important aspect of the practical application of visual representations. However, important and known visual representation principles are often undervalued, which could lead to decreased effectiveness in using a visual representation. Decision Management (DM) is one field of study in which stakeholders must be able to utilize visual notations to model business decisions and underlying business logic, which are executed by machines. In the current body of knowledge, few contributions focus on evaluating visual representation principles to identify the suitability of visual notations for stakeholders. In this paper, the Physics of Notations framework of Moody is operationalized and utilized to evaluate five different DM visual notations. The results show several points of improvement with regards to these visual notations. Furthermore, the results show the authors of DM visual notations that well-known visual representation principles need to be adequately taken into account when defining or modifying DM visual notations. Additionally, operationalization is added extending on the work of** [1].

Keywords-Decision Management; Visual Notations; Evaluation; Physics of Notations (PoN)

I. Introduction

Decisions are amongst the most important assets of an organization [2], and therefore should be managed adequately. A decision is defined as: "*A conclusion that a business arrives at through business logic and which the business is interested in managing*" [3]. Furthermore, business logic can be defined as "*a collection of business rules, business decision tables, or executable analytic models to make individual business decisions*" [4]. Examples of decisions are: 1) diagnose a specific illness a patient has, 2) determine the loan default risk factor for a specific customer, or 3) determine the maximum credit rating of an organization. If an organization cannot consistently make and execute the right decision(s), large risks are taken that can eventually lead to high costs, reputation damage, or even bankruptcy. Following the previous example, imagine what will happen when an MD makes the wrong decision continuously or a customer with a high-risk classification gets a low-risk classification.

One important aspect of Decision Management (DM) is modelling decisions and business logic using a visual representation. Such visual representations are often referred to as notations or modelling standards. An example of a notation to model decisions is the Decision Modeling and Notation (DMN) proposed by the Object Management Group [3] or The Decision Model, defined by von Halle and Goldberg [5].

While empowering the semantic modelling capabilities of notations is desirable, notations also need to be cognitively effective [6]. Cognitive effectiveness, in the context of visual notations, refers to ''*the speed, ease and accuracy with which a representation can be processed by the human mind*'' [7]. Important and known visual representation principles are often undervalued in the design of visual notations, which could lead to decreased cognitive effectiveness [8], [9]. Furthermore, these notations are usually not designed with all stakeholders and their different expertise in mind. For example, someone who never modelled on the one hand (Decision modelling novice) to a Decision modelling expert on the other hand [7]. Modelling novices do have different requirements in comparison to users who are considered an expert [7], [10]. An expert will need more advanced functionalities in comparison to a novice, however, a novice should be able to learn the notation quickly to get started.

This paper examines the cognitive effectiveness of current notations designed for the DM domain. As, to the knowledge of the authors, no earlier studies exist that focus on evaluating multiple DM notations. To do so, a proper framework to evaluate known visual representation principles needs to be selected.

Several frameworks to evaluate visual notations exist, for example, the Cognitive Dimensions (CD) frameworks [11]–[13], Ontological Analysis (OA) frameworks [14], and the Physics of Notations (PoN) framework [7].

OA frameworks consist of a two-way mapping between the visual notation and an ontology. The interpretation mapping describes the mapping from the visual notation to the ontology and the representation mapping describes the inverse comparison [18], [19]. Bunge-Wand-Weber (BWW) ontology is the leading ontology and represents OA frameworks in this study. Multiple OAs have been conducted on different software engineering notations, e.g., [20]–[23]. When conducting an OA, there should be a one-to-one correspondence between a concept in the ontology and the construct in the visual notation. When this is not the case one or more of the following four anomalies will occur [18]: 1) Construct deficit exist when no construct exists which corresponds to a concept during this occurrence the notation is said to be incomplete, 2) Construct overload exists when a single construct can represent multiple concepts, 3) Construct redundancy exists when multiple constructs can represent a single concept, 4) Construct excess when a construct does not correspond to a concept. Ontological clear and complete notations are predicted to be more effective [22]. OAs evaluate the semantics of notations and specifically excludes aspects of visual representation, preferring content above form [7]. OAs cannot distinguish between notations with the same semantics but different syntax. A framework with the ability to differentiate syntax is preferred in the context of evaluating visual notations.

The goal of the CD frameworks is to evaluate the usability of information artefacts and to serve as a guide to create new artefacts [11]–[13]. CD frameworks have theoretical and practical limitations when dealing with the evaluation and designing of visual notations [15]: The frameworks are not created specifically for visual notations, only as a special case (particular class of cognitive artefacts) [16], the dimensions are not specific enough for evaluation, leading to confusion or misinterpretation [16], [17], theoretical and empirical foundations are poorly defined [16], the operationalization of the dimensions is lacking, which makes the application subjective [16], [17], visual representation issues are excluded and are mainly focused on structure [11], evaluation is not supported, the dimensions only define properties and cannot be specified as correct or incorrect [11], [13], design is not supported due to the fact that the dimensions are not guidelines and effectiveness is left out of scope [11], [13], the general level of the CD frameworks excludes specific predictions [11] (unfalsifiable). Due to these limitations, the CD Frameworks do not provide a scientifically fundamental basis for the evaluation of DM visual notations.

The PoN theory [7] is partly based on CD frameworks, which were the predominant theoretical paradigm in visual notations research [24]. PoN is developed and devoted to design, evaluate, and compare visual notations and is based on theory and empirical evidence obtained from different disciplines, such as perceptual psychology, cognitive psychology, cartography, graphic design, human-computer interfacing, linguistics, and communication theory. The PoN framework was specifically developed for visual notations compared to other frameworks which are adapted for this purpose [7]. Therefore, it reduces its generality but supports detailed prescriptions and predictions [7]. Multiple limitations exist for the CD frameworks and the OA frameworks and are developed into mitigating elements of the PoN framework which are the following [7]: 1) symbol-by-symbol analysis is supported in detail, 2) principles are justified explicitly supported by theory and empirical evidence, 3) principles are defined, in detail, and operationalization is supported by evaluation procedures and metrics, 4) desirable properties of visual notations are defined which supports evaluation and makes comparison possible, 5) visual notations could be designed and improved by the provided prescriptive guidelines, and 6) predictions can be generated and empirically tested (falsifiable).

Multiple studies have focused on applying the PoN framework for evaluating visual notations [24][25]. This study focusses on clarifying the criteria of operationalizing the PoN framework. Since we selected the PoN framework to evaluate DM visual notations, the following research question is stated: "*How do the selected DM visual notations score with regards to the PoN framework?*"

The remainder of this paper is structured as follows. First, the theory underlying visual notations and PoN are elaborated upon in the background and related work. This is followed by the research method utilized to conduct the research presented in this paper. Then, the data collection and analysis processes are explained. Next, in the results section, the PoN scores for the selected visual notations are presented. Lastly, the paper concludes with a discussion, conclusions, and directions for future research.

II. BACKGROUND AND RELATED WORK

DM notations can best be categorized by their complexity and linguistic power. Complexity refers to the ease of understanding the DM notation and linguistic power refers to the number of results it can produce, indicating its richness [26]. Five different types of DM notations have been defined [27]: 1) labels, 2) graphical aids, 3) structured languages, 4) constrained natural languages, and 5) pure natural languages, see Fig. 1.

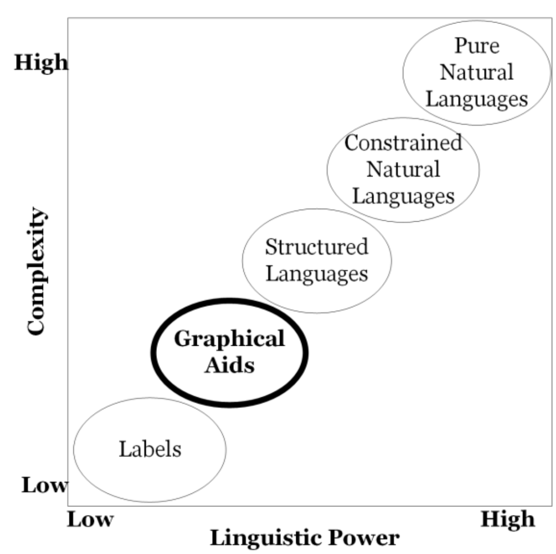

Figure 1. DM notation categorization [27]

The PoN framework attempts to evaluate notations (graphical aids) based on their visual representation, as these are often undervalued principles. It offers nine different principles by which the visual representation of a notation is measured against. The principles are as follows [7]:

Semiotic Clarity refers to every symbol having a one-to-one correspondence to its referent concept. When this is not the case one or more of the following four anomalies will occur: 1) symbol redundancy occurs when multiple symbols can be used to represent the same concept, 2) symbol overload occurs when different concepts can be represented by the same symbol, 3) symbol excess occurs when symbols do not correspond to any concept, and 4) symbol deficit occurs when there are concepts that do not correspond with any symbols.

Perceptual Discriminability refers to the ability to differentiate symbols based on their graphical appearance. This can be improved by increasing the number of graphical attributes a symbol represents. For example, adding colour, additional shapes, or text to a notation can improve the ability to differentiate between symbols.

Semantic Transparency refers to the extent to which the meaning of a symbol can be inferred from its appearance. For example, an icon of a calculator representing a formula has a high Semantic Transparency, while a rectangle representing a decision has a scarce Semantic Transparency.

Complexity Management refers to the ability of a visual notation to represent information without overloading the human brain [7]. The complexity our brain can handle can be improved by the usage of different concepts [21]. Modularization can be used to reduce the complexity of a large system by dividing it into smaller parts or making use of subsystems [21], [28], as shown in Fig. 2. Additionally, a hierarchy can be incorporated into the notation by representing information on different levels of detail.

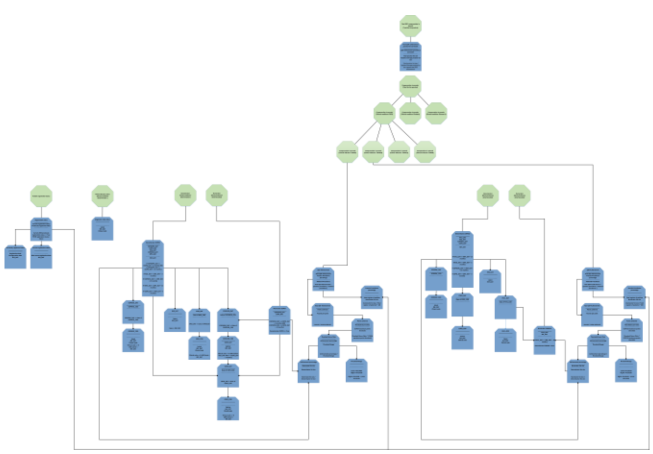

Figure 2. Example of the utilization of modularization in TDM notation [5]

Cognitive Integration refers to the extent to which a notation enables multiple diagrams to represent a system without overloading the human brain. This can be supported by two concepts, conceptual integration and perceptual integration [7]. Conceptual integration can be achieved by providing a summary diagram as a whole or parts of the diagram or by contextualization, a technique where contextual information on each diagram is showing its relation to elements on other diagrams [29], [30]. Perceptual integration is achieved by providing navigational tools in the notation [31]. Commonly used navigational tools are, for example, lines to provide direction of the flow or a map in which the entire diagram is shown if only a part of the diagram is to be shown on the screen.

Visual Expressiveness is defined as the number of visual variables used in a notation [7]. If a notation has a high number of visual variables, the Perceptual Discriminability increases, making the notation easier to use. Visual variables are size, brightness, colour, texture, shape, orientation, and text [7].

Dual Coding refers to the use of both visual and textual attributes in a notation [7]. For example, the Semantic Transparency can be increased by adding a keyword of the semantic concept to the visual representation of the symbol, consequently achieving Dual Coding.

Graphic Economy refers to the number of graphical symbols used in a notation [7]. The human brain can discriminate around six categories simultaneously, defining the limit of graphical symbols a notation should contain [32], [33]. There are three concepts by which excessive graphic complexity can be reduced: 1) reduce semantic complexity, 2) introduce symbol deficit, and 3) increase Visual Expressiveness.

Cognitive Fit refers to the Cognitive Fit theory, which states that different methods of representation of information are suitable for different tasks and different audiences [7]. This can be respected by creating multiple visual filters for, for example, expert-novice differences or representational mediums [34]–[37].

III. RESEARCH METHOD

The goal of this research is to evaluate DM visual notations with regards to the PoN framework [7]. When selecting an appropriate research method, one should take into account the maturity of the research domain [38]. Research with regards to visual notations to express business decisions and business logic is scarce [11]. Therefore, a qualitative research approach is selected as our research method.

Based on the available evaluation frameworks, we selected the PoN framework as the most suitable regarding visual notation evaluation. Based on the PoN framework, the researchers constructed a template (see Appendix A) which covers the nine principles of visual notations indicated in [7]. Each of the nine principles consists of specific elements characterizing each principle, e.g., the principle '*Semiotic Clarity*' has four elements of which one represents '*symbol overload*'. Every principle, and its containing elements, are represented by a question of whether the principle is present in the visual notation and, if present, to what extent. This is evaluated with a five-point Likert-scale or indicated with a percentage.

Instead of a purely quantitative approach to evaluate the DM visual notations, it is more appropriate to use a mix of quantitative collection and analysis with qualitative thematic coding, as our template also aims to collect motivations of researchers evaluating the visual notations and fits with the goal of operationalizing the PoN framework. The coding of the evaluations for the selected visual notations consists of three rounds of pre-defined coding based on a template [39]. During the coding rounds, four researchers coded the five graphical aids-type notations separately from each other. The results of the coding rounds were compared and their meaning discussed among the four researchers. The process of data collection and analysis is described in more detail in the following section.

IV. DATA COLLECTION AND ANALYSIS

Before the data collection and analysis started, the research team needed to decide which visual notations to evaluate. For this study, the number of visual notations to evaluate was five. The DM visual notations are selected based on the following criteria: 1) the notation should be applied in practice by multiple organizations, 2) the documentation for the notation should be accessible to be able to evaluate it in detail, 3) the notations are not a related visual notation (e.g., family of UML) and 4) the notation should be a DM graphical aid type. The following five DM visual notations are randomly selected out of a set of 42 visual notations fitting the previous described criterion: *Beinformed* [40], *Berkeley Bridge* [41], *Decision Model and Notation (DMN)* [3], *The Decision Model (TDM)* [5], and *Visual Rules* [42].

The data collection for this study occurred over a period of two months, between March 2018 and April 2018. The data collection is conducted by four researchers representing different levels of expertise on visual notations. Two researchers representing the expert group (researcher 1 and 2) and two researchers representing the novice group (researcher 3 and 4). Separating the coders increases the inter-reliability in the coding [43] and the internal validity of the research [44]. Besides increasing inter-reliability and inter validity, their position of evaluating if a visual notation can be utilized by an expert or novice should be evaluated as an actual expert or novice. The separation of being an expert or novice user of visual notations is based on the difference of years of research experience and their position in academia [34]–[37], [45], [46]. The most important novice-expert differences are: novices have more difficulty in discriminating symbols [34], [47], novices have to consciously remember the meaning of a symbol [35], complexity affect novices more than experts, as the lack strategies to handle this complexity [48]. Researcher 1 is a lecturer and associate professor with eight years of practical and research experience in the field of DM; Researcher 2 is a PhD-candidate with six years of practical and research experience in the field of DM; Researcher 3 is a Master student with five years of practical and research experience in the field of DM; Researcher 4 is a Master student with three years of research experience in the field of DM. The experts have experience with visual notations and completed at least two or more projects in which DM models had to be produced to be utilized in practice and the novices had little to no experience in actual DM notation projects. It took the research team a week to gather all data required to evaluate the visual notations. The data consisted of webpages, client case documents, learning documents, meta-models, demo applications, and video repositories with tutorials.

A template (included in Appendix A) is created and utilized by the researchers to cover the nine principles of Moody [7]. Every principle with each their own characteristics is further specified in the template with questions to guide the operationalization of the PoN framework. For each element, a five-point Likert-scale ranging from 1) very poor; 2) poor; 3) neutral; 4) good; 5) very good is used. Additionally, the value 6) Not Applicable (NA) could be chosen. If NA was chosen it needed to be further specified why. Therefore, the dataset represents a total of four filled-in templates for each of the five visual notations selected.

The data analysis comprised three rounds of pre-defined coding based on the data analysis techniques described by Strauss & Corbin [39]. The first round of coding identifies the symbols and constructs of each notation, e.g., the different node-types as part of the BeInformed visual notation or the transition-types as part of DMN.

TABLE I. EXAMPLE CODING NOTATION.

		Visual notation: BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Perceptual Discriminability	**Redundant coding**	4	4	4	4
	Perceptual popout	3	4	3	2
	Textual differentiation			2	3
	Iconic differentiation	2	1	3	4

The second round of coding refines and differentiates concepts that are already available and code them into categories [49]. This coding round consisted of the indication of the values (using a five-point Likert-scale) for each visual notation together with the principles of Moody [7], as shown in Table I.

The first and second coding rounds were based on knowledge derived from sources described earlier, however, the coders did not follow courses or applied the visual notation in practice for this specific research.

The third and last round of coding represents the identification of functional categories [49]. This round included the identification of any consistencies or inconsistencies (using the colour grey) within the notations or difference in expertise (expert/novice), as shown in Table I.

The five-point Likert-scale is used to enable calculation of averages used for the comparison of notations, and to create a standard quantification mechanism for the coders to use during the coding of the notations. If doing any quantitative analysis, the Likert-scale is the most accepted and used scale for this purpose [50].

V. RESULTS

In this section, the results from the data collection and analysis phase are shown and further discussed. The results include the differences in values, based on percentages or a five-point Likert-scale, by the coders of different expert levels (expert/novice). The main reason that a five-point Likert scale is utilized is to express the difference of the visual notations for each principle. Table II shows the average of all the analysed visual notations against the nine principles mentioned by Moody [7]. Further on in this section, the results of each PoN principle are discussed in detail. The average totals of the DM notations are influenced by the presence of excess and redundant symbols which is for each a minus one on the total sum before average calculation. Exceeding the graphic economy threshold of six also results in the deduction of minus one on the total sum before average calculation. Different perspectives exist between coders and therefore the occurrence of missing values (no value provided) exists during the evaluation of a notation. This results in the fact that missing values are possible, as shown in Tables III-VI, and X.

TABLE II. CODING RESULTS

		Beinformed	*Visual Rules*	*DMN*	*TDM*	*Berkeley Bridge*
Average Total		**2.87**	**2.97**	**2.38**	**2.89**	**2.53**
Cognitive Integration		2.88	3.83	3.00	2.67	1.92
Cognitive Fit		2.75	2.25	4.13	4.50	3.88
Dual Coding		4.25	4.00	N.A.	N.A.	N.A.
Graphic Economy		16 (-1)	13 (-1)	9 (-1)	4	2
Visual Expressiveness		3.13	4.00	2.25	4.50	1.50
Complexity Management		4.17	3.33	3.83	2.17	3.50
Semantic Transparency		2.88	2.71	2.92	3.56	4.40
Perceptual Discriminability		3.06	2.69	1.50	2.83	2.53
Semiotic Clarity	**Excess**	18.75% (-1)	7.69% (-1)	N.A.	N.A.	N.A.
	Redundancy	18.75% (-1)	N.A.	N.A.	N.A.	N.A.

- **Semiotic Clarity**

A notation with high semiotic clarity does not have any Excess, Deficit, Redundant, or Overload in symbols. Therefore, any occurrence in this is seen as a negative (as shown in Table III). The Beinformed and Visual Rules notation have excess, and/or redundant symbols. The researchers identified 18.75% of the BeInformed symbols as Excess and Redundant, as shown in Table III. The Visual Rules notation was identified with a 7.69% Excess in symbols.

TABLE III. SEMIOTIC CLARITY

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Semiotic Clarity	**Symbol excess in %**	18.75	18.75	18.75	
	Symbol redundancy in %	18.75	25.00	18.75	18.75

An example of a notation with high Semiotic Clarity is Berkeley Bridge as shown in Figure 3; the Berkeley Bridge notation only consists of two symbols.

Figure 3. Example a of notation with high Semiotic Clarity [41]

- **Perceptual Discriminability**

Perceptual Dscriminability covers the use of text, icons, and visual spacing, in order to stimulate faster identification of the different symbols. Therefore, a higher value is an indication that the notation has a high perceptual discriminability and thereby consists of symbols that are identified faster. The BeInformed notation with a 3.06 (as shown in Fig. 4) has the highest Perceptual Discriminability of the analyzed notations, compared to the DMN notation with a 1.50 (lowest). Fig. 4 shows the comparison of the Product, Decision, and Condition symbols used in BeInformed [40] showing the discriminability between the symbols of BeInformed by using text and icons.

Figure 4. Example of notation with high Perceptual Discriminability [40]

The coding of the Perceptual Discriminability of BeInformed is shown in Table IV.

TABLE IV. PERCEPTUAL DISCRIMINABILITY

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Perceptual Discriminability	**Redundant coding**	4	4	4	4
	Perceptual popout	3	4	3	2
	Textual differentiation			2	3
	Iconic differentiation	2	1	3	4

- **Semantic Transparency**

Semantic Transparency covers if the visual appearance of the symbols suggests their meaning. A higher value in this principle is an indication that the notation seems to have semantic transparent symbols. The Berkeley Bridge notation has the highest Semantic Transparency (as shown in Fig. 5) with a 4.4. This seems the result of the low number of symbols, which is two. The BeInformed (as shown in Fig.5) notation seems to be affected by its high number of symbols, and therefore BeInformed is together with Visual Rules then notation with the lowest Semantic Transparency (BeInformed 2.88, and Visual Rules 2.71).

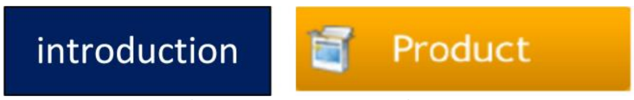

Figure 5. Example of notations with high (left) [41] and low (right) [40] Semantic Transparency

The coding of the Semantics Transparency of Berkeley Bridge is shown in Table V.

TABLE V. SEMANTICS TRANSPARANCY

		Berkeley Bridge			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Semantics transparency	**This symbols are well chosen**	5	4	5	5
	The symbols have to be learnt	5	5	4	4
	The symbols meaning are not obvious				3
	Better symbols should be found				6

- **Complexity Management**

The Complexity Management principle covers the ability to scale the notation for a clearer overview for the user. A higher value in this principle is an indication that the notation is useful with regards to larger systems with multiple diagrams by utilizing modularization and hierarchical structuring. The BeInformed notation has the highest value (4.17) in Complexity Management and is better when dealing with large scale systems with multiple diagrams. The TDM notation seems to be impacted by the low number of symbols in their notation to score the lowest (2.17) in Complexity Management. The coding of the Complexity Management of BeInformed is shown in Table VI.

TABLE VI. COMPLEXITY MANAGEMENT

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Complexity Management	**Moduralization**	4	4	5	5
	Hierarchically structuring				3

TDM is an example of a notation with low Complexity Management as shown in Figure 6.

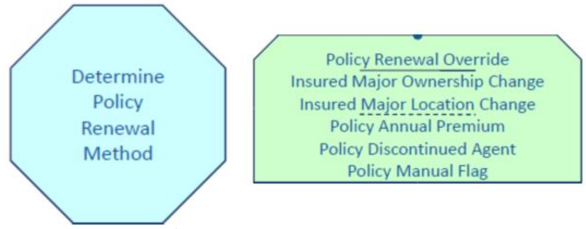

Figure 6. Example of notation with low complexity management. [5]

- **Visual Expressiveness**

The Visual Expressiveness principle covers the use of visual variables (colour, 3d symbols, and textual encoding). A higher value indicates that the notations are visually expressive. The TDM notation has a total score of 4.5 and thereby he highest-scoring notation in Visual Expressiveness, compared to the Berkeley Bridge notation with a 1.5 (lowest). The coding of the Visual Expressiveness of TDM is shown in Table VII.

TABLE VII. VISUAL EXPRESSIVENESS

		TDM			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Visual Expressiveness	**Color**	5	5	4	4

An example of a difference between a high and low Visual Expressiveness notation is shown in Fig. 7. TDM (left) has a high Visual Expressiveness (different colours, the shape of symbols and different use of textual encoding) and Berkeley Bridge (right) a low Visual Expressiveness (one shape symbol and no difference in textual encoding).

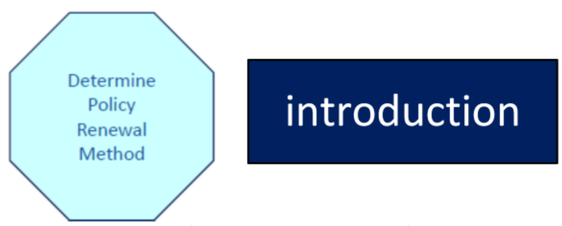

Figure. 7. Example of notations with high (left) [5] and low (right) [41] Visual Expressiveness

- **Graphic Economy**

The Graphic Economy principle covers the number of symbols a human brain is able to discriminate between, this number is estimated to be limited to six. A value above six would be a negative impact on the Graphic Economy of the notation, which is the case for BeInformed (16), Visual Rules (13), and DMN (9). The coding of the Graphic Economy of BeInformed is shown in Table VIII.

TABLE VIII. GRAPHIC ECONOMY

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Graphic Economy	**# symbols**	16	16	16	16

Berkeley Bridge is an example of a notation with a low number of symbols (2), as shown in Figure 3.

- **Dual Coding**

The Dual Coding principle covers the complement of graphics with text, which is more effective than using each of them on their own. A higher value in this principle indicates that the notation utilizes Dual Coding. The Beinformed (4.25) and Visual Rules (4.00) notations are the only notations, out of the analyzed five notations, where Dual Coding was identified. The coding of the Dual Coding of BeInformed is shown in Table IX.

TABLE IX. DUAL CODING

	BeInformed			
	Coders			
	Expert		Novice	
	R1	R2	R3	R4
Dual Coding	4	5	4	4

Visual Rules (shown in Figure 8) is an example of a notation that utilizes Dual Coding.

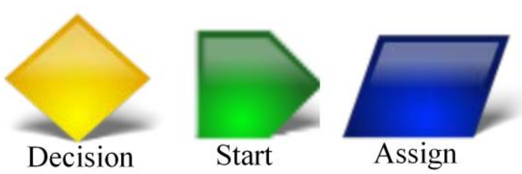

Figure 8. Example of a notation which uses Dual Coding [42]

- **Cognitive Fit**

The Cognitive Fit principle covers the theory that different representations of information are suitable for different audiences. The difference in experience between coders is utilized and classified as expert (R1 and R2) and novice (R3 and R4). The expert and novice coders stated from their experience perspective if there is an expert-novice difference and to what extent (as shown in Table X). The Visual Rules notation scored the lowest with a 2.25, compared to that of TDM, which scored the highest with a 4.50. The coding of the Cognitive Fit of Visual Rules is shown in Table X.

TABLE X. COGNITIVE FIT

		Visual Rules			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Cognitive fit	**expert-novice differences - difference?**	YES	NO	NO	YES
	expert-novice differences - expert/novice?	4	4	3	2
	Representational medium	2	1	1	1

A comparison of notations with high and low Cognitive Fit is shown in Figure 9. TDM (left) with a high Cognitive Fit is indicated by the researchers to be, out of the five notations, the best fit for experts and novices. Visual Rules (right) with a low Cognitive Fit is indicated by the researchers to be, out of the five notations, the least fitted for experts and novices to be utilized.

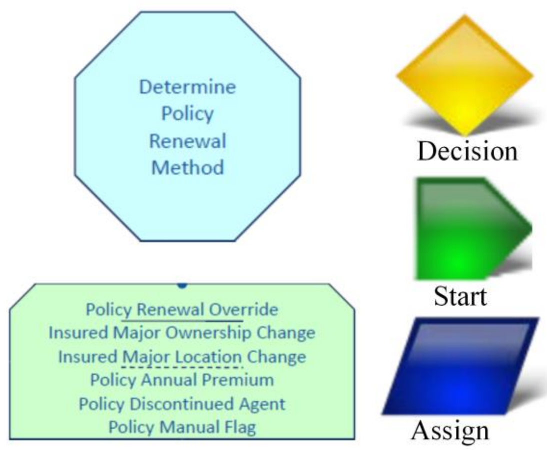

Figure 9. Example of a notation with high (left) [5] and low (right) [42] Cognitive fit

- **Cognitive Integration**

The Cognitive Integration principle covers the range of mechanisms available for dealing with multiple diagrams thereby, helping the reader assemble information from separate diagrams. Concepts supporting are Conceptual Integration (e.g., a summary diagram) and Perceptual Integration (e.g., navigational tools). A higher value indicates that the notation has the mechanisms available to help the reader assemble information when multiple diagrams are shown. The Visual Rules notation (as shown in Fig. 10) has the highest value (3.83) in Cognitive Integration, compared to the Berkeley Bridge (as shown in Fig. 10) notation (1.92) which does not have the mechanisms to support the reader when dealing with separate diagrams (lowest).

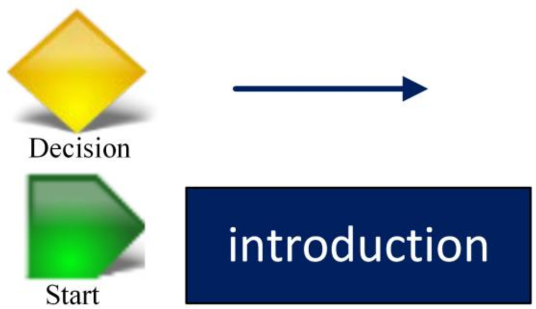

Figure 10. Example of a notation with high (left) [42] and low (right) [41] Cognitive Integration

The coding of the Cognitive Integration of Visual Rules is shown in Table XI.

TABLE XI. COGNITIVE INTEGRATION

		Visual Rules			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Cognitive Integration	**Perceptual integration**	4	4	4	4
	Conceptual integration				3

- **Difference expert/novice**

Taking into account that having experience in the use of a visual notation, in this case, a modelling language, influences the attitude towards several of the Moody principles. For example, a notation could be more complex for a novice but not for an expert. Therefore, a difference is made between the results of the expert researchers and novice researchers. The coding of the difference between expert and novice is shown in Table XII.

TABLE XII. RESULTS DIFFERENCE EXPERT/NOVICE

	Expertise:	**Average Total Expert/Novice**	**Average Total**
Beinformed	**Expert**	2.79	2.87
	Novice	2.95	
Visual Rules	**Expert**	2.99	2.97
	Novice	2.96	
DMN	**Expert**	2.25	2.38
	Novice	2.51	
TDM	**Expert**	2.92	2.89
	Novice	2.86	
Berkeley Bridge	**Expert**	2.39	2.53
	Novice	2.67	

VI. CONCLUSION, DISCUSSION AND FUTURE RESEARCH

In this paper, a study is conducted in which five DM visual notations, namely: Visual Rules, Berkeley Bridge, Decision Model and Notation, The Decision Model, and BeInformed, were evaluated using the PoN framework [7]. From our analysis, Visual Rules scores best according to the average total of all PoN framework principles. From a theoretical perspective, our study and its results give meaning to the operationalization of the PoN framework. Furthermore, it will enable further exploration of the application of the PoN principles, as well as other DM visual notations not included in this study. Moody [1, p.772] describes the theoretical interactions between the described principles. Our results show that these interactions are, to a large extent, verified. From a practical perspective, the results presented in this paper contribute towards a better awareness for taking into account validated visual notation principles and guidelines. Our results could be utilized by organizations to either evaluate for themselves which visual notation is most adequate or to utilize a visual notation based on our results.

This study has multiple limitations. The first limitation concerns the research team that carried out the evaluation of the visual notations using the PoN framework. This study included evaluations of four researchers, two novice level researchers and two expert-level researchers on the DM topic. Therefore, one could argue that the results and conclusions are potentially biased by a low amount of data points for the evaluation of the visual notations included. However, most studies conducted with a focus on evaluating one or multiple visual notations are often centred on the evaluation of the visual notation using one or two researchers [24], [25], [51]. Future research should focus on evaluating visual notations utilizing a larger sample of participants that will add to the generalizability of the results and conclusions about the evaluated visual notations.

The second limitation concerns the method and framework utilized to evaluate the visual notations, the PoN framework and its operationalization by creating and utilizing a template with the goal to structure data collection and analysis. Utilizing the PoN framework is an explicit choice, however, limits the results because the PoN framework represents a specific lens. Future research could, therefore, focus on applying other frameworks and theories that focus on uncovering and describing essential notational principles, e.g., Guidelines of Modeling (GoM) [52]. Furthermore, the operationalization of the PoN framework described in [7] is left open for interpretation and perception of the researchers applying it, a good example is the lack of weighting of the nine PoN principles. Therefore, our template is another limitation. This phenomenon becomes clear in the work of [6], which shows that the operationalization of the PoN framework by different research teams often do not always seem to take into account all principles described. This is tackled by utilizing the created template in this study, see Appendix A. Future research, however, should focus on how these principles are best measured in practice, i.e., whether Likert scales or other less quantitative measurements are adequate or not. A first step is taken with the addition of user scenarios to support the operationalization of the PoN framework.

The last limitation concerns the visual notations selected. Although we choose two well-known visual notations, as well as three visual notations applied in the DM practice a lot, the selection of visual notations could coincidentally have resulted in bias and affect the generalizability of our results. We argue that this risk is more or less mitigated as most studies conducted that utilize the PoN framework focus on only one visual notation, see also [6], while this study reports upon the evaluation of five visual notations. Future research could also focus on evaluating additional DM visual notations.

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APPENDIX A – TEMPLATE CHECKLIST GRAPHICAL NOTATIONS

I. INTRODUCTION

This is the template for the checklist. The checklist is based on the theory of "The Physics of Notations" [7]. Therefore, before using this template it is required to have read "The Physics of Notations" [7] paper. The structure of this document is derived from the following figure:

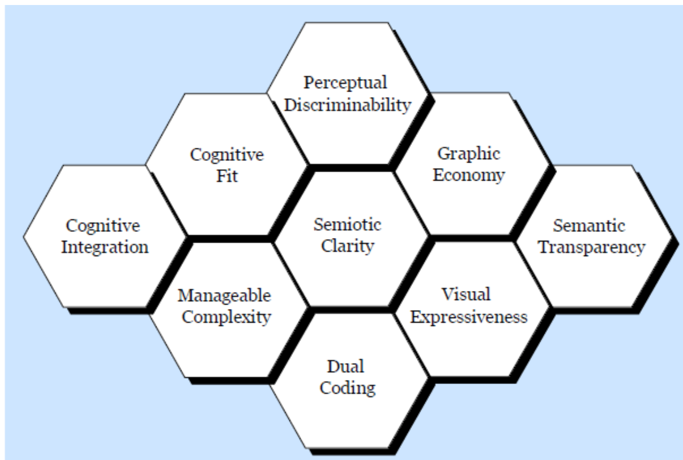


Figure 1 - The Physics of Notations [7]

In addition, this template makes use of a five-point scale for the assessment of the properties of the notations, wherein the numeral 1= very poor, 2=poor, 3= poor/good, 4=good, and 5=very good. Some concepts start with a question if the concept occurs in the notation, these questions should be answered with yes or no. If the answer is yes, the 5-point Likert scale should be applied.

At the end of the document, we inserted a section named “Additional notes”. In this section you can provide us extra information besides the information needed by the template about the notation.

II. SEMIOTIC CLARITY

According to Goodman’s theory of symbols, for a notation to satisfy the requirements of a notational system, there must be a one-to-one correspondence between symbols and their referent concepts. When there is not a one-to-one correspondence between constructs and symbols, one or more of the following anomalies can occur:

- **Symbol excess** occurs when graphical symbols do not correspond to any semantic construct.
- **Symbol deficit** occurs when there are semantic constructs that are not represented by any graphical symbol.
- **Symbol redundancy** occurs when multiple graphical symbols can be used to represent the same semantic construct.
- **Symbol overload** occurs when two different constructs can be represented by the same graphical symbol.

Step 1: List all the symbols used by the notation.

Symbol

Step 2: Name the symbols to their corresponding semantic construct.

Number	Symbol construct	Symbol(s)

Step 3: Link construct types to their symbols and symbol construct

Symbol construct	Construct type	Symbol(s)	Number

Step 4: Semiotic clarity analysis (calculate defects)

- **Symbol excess** occurs when graphical symbols do not correspond to any semantic construct.
- **Symbol deficit** occurs when there are semantic constructs that are not represented by any graphical symbol.
- **Symbol redundancy** occurs when multiple graphical symbols can be used to represent the same semantic construct.
- **Symbol overload** occurs when two different constructs can be represented by the same graphical symbol.

Semiotic clarity summary:

Defect	Occurrences	Percentage
Symbol excess		
Symbol deficit		
Symbol redundancy		
Symbol overload		

III. PERCEPTUAL DISCRIMINABILITY

Perceptual discriminability is the ease and accuracy with which graphical symbols can be differentiated from each other. This relates to the first phase of human visual information processing: perceptual discrimination. Accurate discrimination between symbols is a prerequisite for accurate interpretation of diagrams.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Gather the visual variables per symbol.
  Describe the symbols VV's (Visual Variables) in the following table(s).

Symbol construct	Symbol	Visual variable values		Semantics carrier
		(x, y):		
		Shape:		
		Colour:		
		Brightness:		
		Size:		
		Orientation:		
		Texture:		

* A table should be completed for each symbol, when more are needed, copy the table above.

A. Redundant coding

Redundancy is an important technique in communication theory to reduce errors and counteract noise. The visual distance between symbols can be increased by redundant coding: using multiple visual variables to distinguish between them. As an example, colour could be used to improve discriminability between entities and relationships in ER diagrams

- **Step 2:** Describe redundant coding.
  Describe the possibilities regarding redundant coding in the following table(s).

Redundant coding present in notation?	Grade	Motivation

B. Perceptual popout

According to feature integration theory, visual elements with unique values for at least one visual variable can be detected pre-attentively and in parallel across the visual field. Such elements appear to "pop-out" from a display without conscious effort. On the other hand, visual elements that are differentiated by unique combinations of values (conjunctions) require serial search, which is much slower and error-prone.

- **Step 3:** Perceptual popout
  Describe the possibilities regarding perceptual popout in the following table(s).

Perceptual popout present in notation?	Grade	Motivation

C. Textual differentiation

SE notations sometimes rely on text to distinguish between symbols. For example, UML frequently uses text and typographic characteristics (bold, italics, underlining) to distinguish between element and relationship types.

- **Step 4:** Textual differentiation
  Describe the possibilities regarding textual differentiation in the following table(s).

Textual differentiation present in notation?	Grade	Motivation

D. Iconic differentiation

Icons are symbols that perceptually resemble the concepts they represent. This reflects a basic distinction in semiotics, between symbolic and iconic signs. Iconic representations speed up recognition and recall and improve intelligibility of diagrams to naïve users. They also make diagrams more accessible to novices: a representation composed of pictures appears less daunting than one composed of abstract symbols. Finally, they make diagrams more visually appealing: people prefer real objects to abstract shapes.

- **Step 5:** Iconic differentiation
  Describe the possibilities regarding iconic differentiation in the following table(s).

Iconic differentiation present in notation?	Grade	Motivation

IV. SEMANTICS TRANSPARENCY

Semantic Transparency is defined as the extent to which the meaning of a symbol can be inferred from its appearance. While Perceptual Discriminability simply requires that symbols should be different from each other, this principle requires that they provide cues to their meaning (form implies content). The concept of Semantic Transparency formalizes informal notions of "naturalness" or "intuitiveness" that are often used when discussing visual notations, as it can be evaluated experimentally.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Transparency regarding the notations symbols.
  Describe the transparency of the symbols used by the notation in the following table(s).

Symbol		
	1. This symbol is well-chosen 2. The symbol has to be learnt 3. The symbol's meaning is not obvious 4. A better symbol should be found	
	Grade	
	Motivation	

* A table should be completed for each symbol, when more are needed, copy the table above.

V. COMPLEXITY MANAGEMENT

Complexity Management refers to the ability of a visual notation to represent information without overloading the human mind. Complexity is also one of the defining characteristics of the SE field, where complexity levels exceed those in any other discipline.
To describe the notation's score for this principle, perform the following step(s):

A. Modularization

The most common way of reducing complexity of large systems is to divide them into smaller parts or subsystems: this is called modularization.

- **Step 1:** Modularization within the notation.
  Describe the possibilities regarding modularization in the following table(s).

Modularization possible in notation?	**Grade**	**Motivation**

B. Hierarchically structuring

Hierarchy is one of the most effective ways of organizing complexity for human comprehension as it allows systems to be represented at different levels of detail, with complexity manageable at each level. This supports top-down understanding, which has been shown to improve understanding of SE diagrams.

- **Step 2:** Modularization within the notation.
  Describe the possibilities regarding hierarchically structuring in the following table(s).

Hierarchically structuring possible in notation?	**Grade**	**Motivation**

VI. VISUAL EXPRESSIVENESS

Visual Expressiveness is defined as the number of visual variables used in a notation. This measures utilisation of the graphic design space.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Describe Visual Expressiveness
  Describe the notation's Visual Expressiveness by filling in the following table(s).

Is colouring used in the notation? (YES/NO)	**Grade**	
Motivation		

Are 3d symbols used in the notation? (YES/NO)	**Grade**	
Motivation		

Is textual encoding of information used in the notation? (YES/NO)	**Grade**	
Motivation		

Are there visual dependency variations in the notation? (YES/NO)	**Grade**	
Motivation		

VII. GRAPHIC ECONOMY

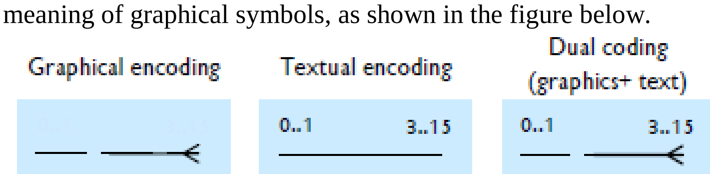
Graphic complexity is defined by the number of graphical symbols in a notation: the size of its visual vocabulary.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Describe the Graphic Economy.
  Describe the notation's Graphic Economy by filling in the following table(s).

Amount of basic shapes	**Amount > 6**
#	Yes/no
Motivation	

VIII. DUAL CODING

Perceptual Discriminability and Visual Expressiveness both advise against using text to encode information in visual notations. However, this does not mean that text has no place in visual notation design. Pictures and words are not enemies and should not be mutually exclusive. According to Dual Coding theory, using text and graphics together to convey information is more effective than using either on their own. Textual encoding can be used to reinforce and expand the meaning of graphical symbols, as shown in the figure below.



To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Determining the possibilities of Dual Coding.
  Describe the possibilities regarding Dual Coding in the following table(s).

Dual Coding possibilities within notation?	**Grade**	
Motivation		

IX. COGNITIVE FIT

Cognitive Fit theory states that different representations of information are suitable for different tasks and different audiences. Problem-solving performance (which corresponds roughly to cognitive effectiveness) is determined by a three-way fit between the problem representation, task characteristics and problem solver skills.
To describe the notation's score for this principle, perform the following step(s):

A. Expert-novice differences

One of the major challenges in designing SE notations is the need to develop representations that are understandable by both business and technical experts. This adds to the difficulty of the task as in most engineering contexts, diagrams are only used to communicate among experts.

- **Step 1:** Describe the differences between novice and expert users.
  Describe the possibilities regarding expert-novice differences in the following table(s).

Is there a difference between novice and expert use? (YES/NO)			
How do you grade the use as an expert or novice?		**Grade**	
Motivation			

B. Representational medium

Another situation that may require different visual dialects is different representational media. In particular, requirements for sketching on whiteboards or paper (an important use of visual notations in early design stages), are different to those for using computer-based drawing tools. Some of the most important differences are:
Perceptual Discriminability: discriminability requirements are higher due to variations in how symbols are drawn by different people. As within-symbol variations increase, between-symbol differences need to be more pronounced.
Semantic Transparency: pictures and icons are more difficult to draw than simple geometric shapes, especially for the artistically challenged.
Visual Expressiveness: some visual variables (colour, value and texture) are more difficult to use (due to limited drawing ability and availability of equipment e.g., colour pens).

- **Step 1:** Determining the difficulty of transferring information between users in the notation's language.
  Describe the possibilities (and difficulty) regarding the notation as a representational medium in the following table(s).

Representational medium		**Grade**	
Motivation			

X. COGNITIVE INTEGRATION

Cognitive Integration only applies when multiple diagrams are used to represent a system. This is a critical issue in SE, where problems are typically represented by systems of diagrams rather than single diagrams. It applies equally to diagrams of the same type (homogeneous integration) – for example, a set of levelled DFDs – or diagrams of different types (heterogeneous integration) – for example, a suite of UML diagrams or ArchiMate views.
To describe the notation's score for this principle, perform the following step(s):

A. Perceptual integration

Perceptual integration: perceptual cues to simplify navigation and transitions between diagrams. There are a range of mechanisms that can be used to support perceptual integration, which draw on the design of physical spaces (urban planning), virtual spaces (HCI) and graphical spaces(cartography and information visualization). Whether navigating around a city, a website, an atlas, or a set of diagrams, wayfinding follows the same four stages:

- **Orientation**: where am I?
- **Route choice**: where can I go
- **Route monitoring**: am I on the right path?
- **Destination recognition**: am I there yet?

Step 1: Determining the perceptual integration.
Describe the possibilities regarding perceptual integration in the following table(s).

Perceptual integration possible?		**Grade**	
Motivation			

B. Conceptual integration

Conceptual integration: mechanisms to help the reader assemble information from separate diagrams into a coherent mental representation of the system. One important mechanism to support conceptual integration is a **summary (longshot) diagram**, which provides a view of the system as a whole.

- **Step 1:** Determining the conceptual integration.
  Describe the possibilities regarding conceptual integration in the following table(s).

Conceptual integration possible?		**Grade**	
Motivation			

XI. ADDITIONAL NOTES

Perceptual and Reproductive Learning for Line Drawing Strokes Using Active Wheel-Based Finger Tactile Interface

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Abstract—**The goal of this paper is to establish an intensive training procedure for improving subjects' tactile-motor performance for an active wheel-based finger tactile interface. The methodology for achieving the goal is to propose a training procedure, and to show perceptual learning characteristic improvements as a result of the intensive training. Concretely, subjects repeated a tactile-motor learning trial composed of a slippage perception and a stroke reproduction. That is, a learning trial is constituted of four steps: (1) a target hand-stroke, i.e., a uniform motion, is presented as a slippage by the active-wheel-based finger-tactile interface, (2) a subject reproduces the slippage as a hand-stroke, (3) accepting the slippage corresponding to the subject-reproduced stroke, the subject improves their slippage sensitivity, (3) accepting the initial slippage corresponding to the target hand-stroke, the subject furthermore improves their slippage sensitivity. The training had been conducted for eight days, three sessions a day, 16 learning trial a session. As a result of a psychophysical experiment with eight subjects involving an intensive eight-day training, the subjects significantly improved their slippage-perception and stroke-reproduction ability. The 1st day training doubled the perceptual sensitivities: the sensitivities were defined by a ratio of an estimated slope to the standard error with respect to the reproduced stroke speed, by another ratio with respect to the time-duration, and by the standard deviations with respect to the reproduced stroke angular error. Furthermore, the intensive eight-day training made the speed-perceptual sensitivity two-times better than that after the 1st day training. Thus, a learning effect was significantly observed, and, consequently, the effectiveness of the proposed training procedure was confirmed.**

Keywords—slippage perception; tactile interface; stroke reproduction; training and learning; dominant and non-dominat hand assignment.

I. Introduction

In the previous paper by Nomura et al. [1], a line drawing perceptual characteristic using an active-wheel mouse (AWM) was presented on the relationship to the number of strokes: the AWM was a mouse interface to which active wheel-based finger tactile (AWFT) interface was attached. [2] [3] [4] [5] [6]. This paper is an extended version of the previous paper. In this paper, the AWFT interface was not attached to a mouse, but was used in a stand-alone as a static interface. Moreover, an intensive training protocol for perceptual learning with the AWFT interface was proposed.

Once we lose our vision, we shall suffer inconveniences in daily life. Visually impaired persons utilize their sensations other than the vision such as skin-sensations and proprioceptive sensations. Similarly, many assistive devices have been developed as an alternative for vision.

Some handy-and-portable tactile devices have also been proposed for character presentation and walking route guidance. For instructing arm motions, Tsuda et al. [7] and Causo et al. [8] proposed a vibrotactile device. Norman et al. [9] proposed a skin-stretch device. Gleeson et al. [10] proposed a skin stretch-based tactile display in conjunction of a joystick-based force feedback, and Koslover et al. [11] combined a skin stretch-based tactile display with vibrotactile and voice guidance. Ion et al. [12] proposed a tactile display to drag a physical tactor across the skin for instructing geometrical shapes. Tsagarakis et al. [13] proposed a slippage display to rotate two cones for instructing 2D directions. Moscatelli et al. [14] proposed another slippage display to rotate a ball for instructing 2D slippages.

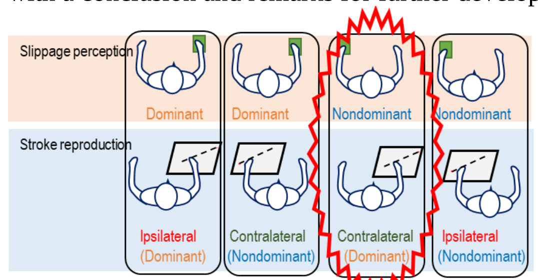
They provided motion information with tactors. However, they could not solve the following problems: ① the number of physical properties to be presented was restricted in such way that only a motion direction can be presented, ②the operating range was restricted in several millimeters. As a solution for the problems, the authors have presented the AWFT interface [4] [5]" and an "After-Recognition Go (ARG)" presentation strategy [2] [3].

Recently, based on the ARG presentation strategy, the reproduction performances, i.e., the accuracies in the speed, time-duration, and direction of the reproduced strokes, were compared between four kinds of hand assignments on perception-and-reproduction task. That is, while the AWFT interface presented slippages to an index finger pad of either a dominant or non-dominant hand, users perceived the slippages and recognized them as strokes. Next, the users reproduced the recognized strokes with either a dominant or non-dominant hand. As a result, a hand-assignment by the non-dominant for perception and dominant for reproduction (NDP&DR hand-assignment) was found to be superior to the other three hand assignments because the proportional coefficient of the reproduced stroke speed against the presented stroke speed by the NDP&DR hand-assignment was nearest to the ideal value of one than the other three hand-assignments as shown in Figure 1—in the NDP&DR hand-assignment, users perceived the slippages by their index finger pad of their non-dominant hand, and reproduced the recognized strokes by their dominant hand.

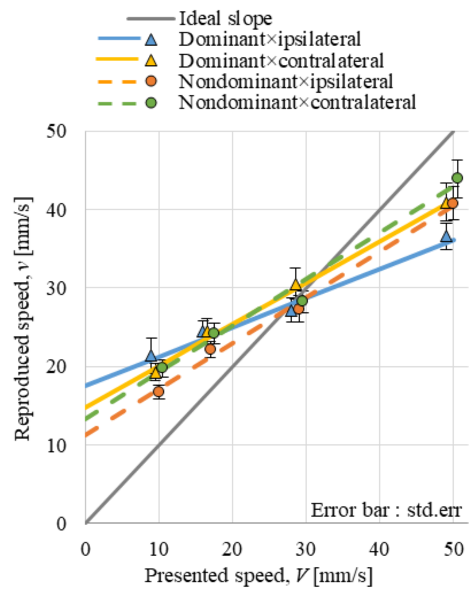
In this experiment, the NDP&DR hand-assignment and the ARG presentation-strategy were employed as elementary procedures that are repeated in an intensive learning protocol.

Some studies on perceptual learning were carried out as follows. Wong et al. reported a learning effect with respect to a tactile interface that presents square-wave gratings as horizontal or vertical stimuli on a small area of fingerpad and lip [15]. They confirmed a tactile experience-based hypothesis that blind participants who have a lot of tactile experience would outperform the sighted participants on the fingers, and that Braille reading would correlate with the tactile acuity. Using the same apparatus, they furthermore, conducted an experiment involving an intensive training where participants completed 1900 training trials (38 blocks ×50 trials) during four days [16]. As a result, they concluded a hypothesis that tactile perceptual learning is limited by finger size. That is, participants' tactile spatial acuity improved toward a theoretical optimum value defined by their finger size: participants with worse initial performance relative to that corresponding to their finger size improved more with training, and post training performance was better correlated than pre-training performance. Harrar et al. reported an interesting result on the so-called transfer learning regarding the extent to which tactile perceptual learning was generalized across fingers [17]. They measured tactile orientation discrimination abilities in each of the four fingers (index and middle fingers of both hands) before and after a training procedure. In the training procedure, 4 tactile gratings were chosen, based on the threshold calculated from the first testing session, and based on performance in the previous training sessions (Sessions 2 through 4) thereafter. Participants completed 576 trials (4 day-sessions × 12 blocks (4 gratings widths × 3 block repetitions) × 12 trials). As a result, following training, performance was improved not only for the trained fingers, but also for its adjacent and homologous fingers. These findings gave us a motivation of taking up to confirm the learning effect on improving perceptual sensitivities with an intensive training for the author-developed AWFT interface as in this paper.

The remainder of the paper is structured as follows. Section II outlines a brief mechanical design of our developed AWFT interface and some methodologies for the interface, i.e., the ARG presentation-strategy and the NDP&DR hand-assignment. Section III introduces a protocol for perceptual learning with the AWFT interface. Next, in Section IV, an experiment follows the system descriptions. The paper closes with a conclusion and remarks for further developments.



(a) Four kinds of assignments of either dominant or non-dominant hand to perception and reproduction task.



(b) The nondominant×contralateral assignment, i.e., non-dominant-for-perception and dominant-for-reproduction, shown by the yellowish green-colored broken line was concluded to be best in the four assignments, achieving the highest slope of the reproduced speed to the presented one.

Figure 1. Characteristics of reproduced speed for the four kinds of perception×reproduction assignments [6]

II. Active Wheel-Based Finger Tactile Interface

In this section, a brief mechanical design of the AWFT interface is first described. Nest, methodologies for utilizing the interface, i.e., the ARG presentation-strategy and the NDP&DR hand-assignment, are introduced.

A. *Apparatus*

We have previously presented an AWFT interface [5]: a specific tactile interface as shown in Figure 2. A wheel is embedded in the tactile interface, and the diameter and thickness of the wheel are 20 mm and 6 mm, respectively (see Figure 3). Raised dots are formed on the wheel peripheral surface to enhance slippage perception: the height of the raised dots is 0.5 mm, and the diameter of the bottom circle is 1.7 mm. The dot interval was 10.5 mm so that the dots appear one by one on the fingerpad because one-by-one appearance made the slippage perception easier as in Nomura et al. [18][19]. The tactile interface rotates a wheel around the wheel central axis in any horizontal direction by two stepping motors (M15SP-2N and M25SP-6NK (Mitsumi Electric Co., LTD., Tokyo, Japan) (see Figure 4). Installed in a wheel rotating part, the former stepping motor rotates the wheel, while the latter stepping motor swivels the wheel rotating part. The rotation and swivel result in a velocity and direction of wheel slippage on fingerpad, respectively. The velocity together with the time duration decides slippage length.

B. *ARG Line-Drawing-Stroke Presenting Strategy*

The ARG presentation-strategy for presenting line-drawing strokes was employed as in the following [3].

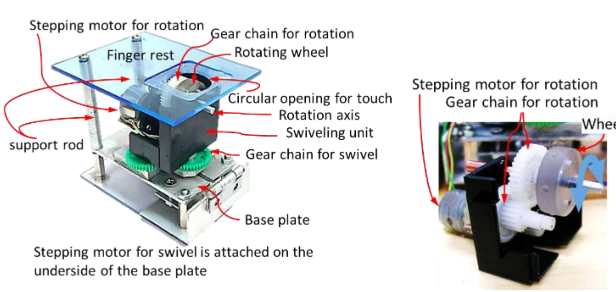
[Step 1] Subjects put the wrist of their non-dominant hand on a resting stage —as was recommended by the result that a NDP&DR hand-assignment was superior to the other hand-assignments [6]: users perceived the slippages by their index finger-pad of their non-dominant hand, and reproduced the recognized strokes by their dominant hand. Since all the subjects were right-handers in this experiment, the non-dominant and dominant hand correspond to the left and right hand.

[Step 2] The AWFT interface swivels the swiveling unit in a given direction.

[Step 3] The subjects touch their index finger-pad of their non-dominant hand on the wheel periphery.

[Step 4] The AWFT interface rotates the wheel with a uniform angular velocity and in a time-duration. While accepting the slippage stimulus induced by the rotation (see Figure 5 (a)), the subjects recognize the stimulus as a stroke with a uniform-velocity straight-line motion. In particular, the subjects focus their attention to the speed, time-duration, and angle of the presented slippage. Here, note that the circumference of the wheel is circular, and the actual locus of the slippage is an arc. Yet, since it is not easy for us to perceive the arc-shaped slippages, users were instructed not to perceive the slippage as an arc segment, but as a straight-line segment.

[Step 5] Just after the wheel rotation finished, the subjects draw a straight line on a touch panel display (TPD) using a stylus pen held by the dominant hand (see Figures 5 (b) and (c)).



(a) AWFT tactile interface. (b) Swiveling unit (Wheel-rotating part).

Figure 2. General view of AWFT interface

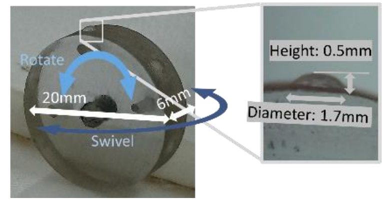
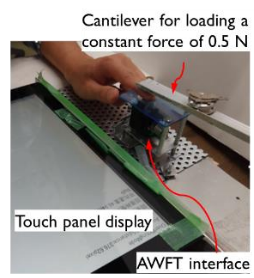
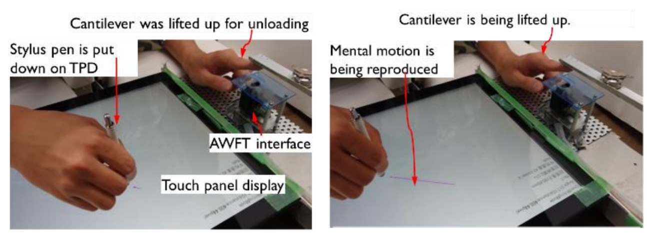


Figure 3. Wheel configuration: raised dots are formed on wheel periphery.

Figure 4. Stepping motor and gear-chain units for rotation and for swivel.



(a) Accepting wheel rotation, a subject creates a mental image of a presented slippage.



(b) Subject puts down a stylus pen on a TPD screen.

(c) Subject traces the mental image on the TPD with the stylus pen.

Figure 5. ARG presentation-strategy for line drawing stroke learning.

III. Protocol for Perceptual-and-Reproductive Learning with AWFT Interface

A representative application of the slippage presentation by the AWFT interface is to instruct users on line-drawing strokes. In making line-drawing strokes, there are two processes: one is a slippage-perceiving process and the other is a handstroke-making process based on the perceived slippages. Therefore, in order to improve the performance of making line-drawing strokes, the sensitivity of slippage perception and stroke reproduction is to be enhanced in a combined form.

The perceptual-and-reproductive learning with the AWFT interface was carried out in eight days as shown in Figure 6: the eight days are concentrated, but consecutive, and a few days of breaks were involved in a schedule being different from subject to subject. In order to make the learning effect explicit, the period of eight days was designed, based on a preliminary experiment employing three subjects other than the subjects in this paper.

In the first day, before learning, the experimenter explained the task to the participants. Then, the participants were asked to repeat the task until they understood the procedure, and considered themselves to be familiarized with the slippage-perception using the NDP&DR hand-assignment.

Next, in each of the training days, three training sessions were consecutively iterated, accompanied by a pre-test and post-test session. The sessions are constituted of 16 trials, and each trial is given by Steps 1 to 4 in training, while that is given by Steps 1 and 2 in testing, as shown in Figure 7.

[Step 1] Aiming at a target hand-stroke, an AWFT-interface presents a slippage, called a first slippage. Since the subject does not know of the true value of the first slippage, the learning for the slippage sensitivity can be regarded as an unsupervised learning. While perceiving the initial slippage, a subject memorizes it as a translational motion, called a first mental motion where a slippage perceptual error is involved. The slippage perceptual error is to be reduced after perceptual learning.

[Step 2] While recollecting the first mental motion, the subject reproduces the mental motion as a hand-stroke on a TPD with a stylus. In this process, proprioceptive error is involved, which would be much smaller than the slippage-perceptual error, and is not considered.

[Step 3] The AWFT-interface presents a second slippage corresponding to the subject-reproduced hand-stroke. The subject perceives the second slippage and recognizes as a second mental motion, where another slippage perceptual error is involved. Next, comparing the second mental motion to the first one, the subject modifies their slippage perceptual sensitivity so as to match them. Since the second slippage corresponds to the hand-stroke reproduced by the subjects themselves, the sensitivity learning can be regarded as a supervised.

[Step 4] The AWFT interface again presents the first slippage. Based on the modified sensitivity, the subject again perceives the first slippage, and recognizes it as a third mental motion. Next, comparing the third mental motion to the second one, the subject furthermore modifies their slippage perceptual sensitivity so as to match the second to the third mental motion. Since the subject can compare the third with second mental motion, the sensitivity learning can be regarded as another supervised learning.

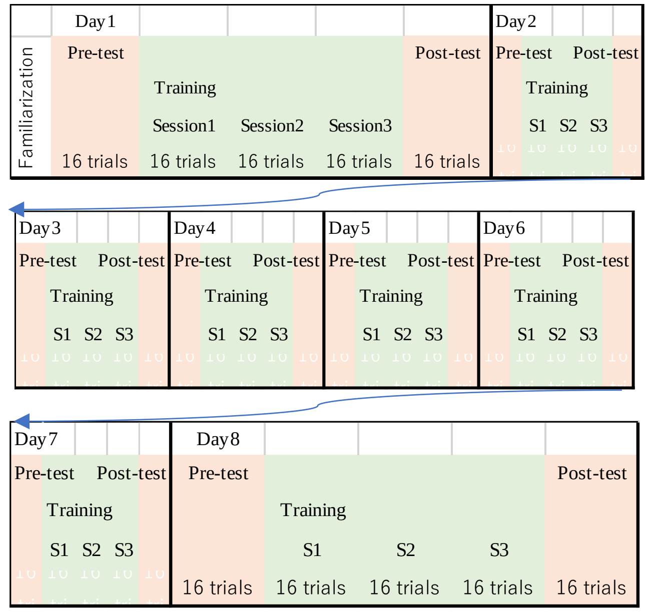


Figure 6. Protocol of an eight-day sensitivity training of slippage perception and stroke reproduction for a single straight line-drawing-stroke.

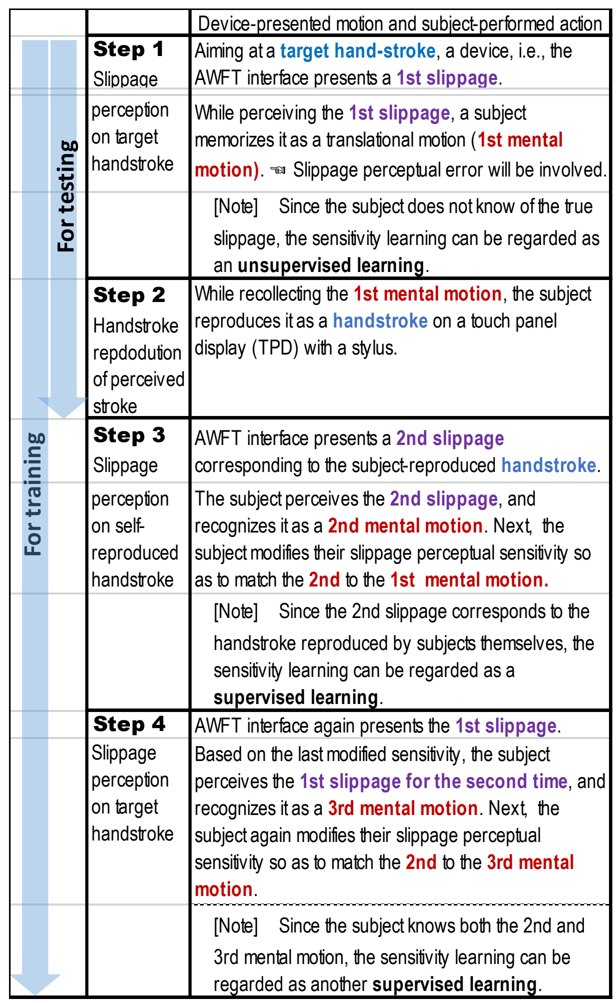


Figure 7. Protocol of a sensitivity-training trial constituted of Steps1 to 4 and that of the pre/post test trial constituted of Steps 1 and 2.

IV. EXPERIMENT

In this section, an experimental method to confirm an effectiveness of the sensitivity training is first explained, and, then, experimental results of the sensitivity training are described.

A. Experimental Method

1) Experimental conditions

Eight healthy right handed males in their 20s (20~25, mean=21.8, standard deviation (SD) =1.5) participated in the experiment. All the participants gave signed consent and received monetary compensation. All procedures were approved by Research Ethics Committee of Graduate School of Engineering, the Mie University.

The three training sessions and the pre- and post-test session consist of 16 trials. In the 16 trials, 16 different slippages that represent different single straight-strokes were presented with the AWFT interface: the levels of the speed, time-duration and angle factor were given by an orthogonal array of n = 128 (4 factors of 5 levels and 1 factor of 8 levels) where the subject was also assigned to the eight-level factor in the orthogonal array. The 16 slippage patterns were different between testing and training, and between the subjects, while, for each subject, the 16 slippage pattern was identical throughput the training sessions, i.e., from the 1st training session in the 1st day to the final 3rd training session in the 8-th day. Similarly, the 16 slippage pattern was identical from the pre/post-test session in the 1st day to the post/post-test session in the 8-th day.

The elapsed time for one day training was approximately 60 min, and no subjects reported that they did not feel to be tired to an extent that they suffered any ill effects in their performance. Practically, considering the subjects' response, the one-day training schedule composed of three-training and two-testing sessions was designed.

TABLE I. FACTORS AND FACTOR LEVELS EMPLOYED IN EXPERIMENT.

Factor	Factor level
Presentation strategy	After-recognition go strategy
Hand assignment	Slippage-perception with a non-dominant hand and stroke reproduction with a dominant hand (NDP&DR hand-assignment)
Presented line drawing stroke	Single stroke by uniform motion
Time duration [s]	4 levels: 1.0, 1.7, 2.9, 5.0
Speed [mm/s]	4 levels: 10, 17, 29, 50
Direction [deg]	16 levels: 0, 22.5, 45,, 315, 337.5

2) Evaluation values

The presented stroke length, $l_{presented}$, and time-duration, $\tau_{presented}$, are related to the presented speed $v_{presented}$ by

$$v_{presented} = l_{presented} / \tau_{presented} \quad (1)$$

On the other hand, we obtained a secant from a subject-reproduced stroke—the word "secant" represents the line segment connected from a start to an end. Next, for the secant of the reproduced stroke, we measured the length $l_{reproduced}$ and angle $\theta_{reproduced}$. In addition, a time-duration $\tau_{reproduced}$ of the reproduced stroke was obtained from a time record. Then, using $l_{reproduced}$ and $\tau_{reproduced}$, the speed of the reproduced stroke $v_{reproduced}$ is given by

$$v_{reproduced} = l_{reproduced} / \tau_{reproduced} \quad (2)$$

Then, taking an example of velocity, a procedure of modelling is explained with respect to the reproduced strokes. That is, by applying a linear least-squares method to the pairs of $v_{reproduced}$ and $v_{presented}$, a linearly modelled value of the reproduced stroke speed, $v_{modelled}$, is given by

$$v_{modelled} = s_v \, v_{presented} + i_v \quad (3)$$

where s_v and i_v are a slope and an intercept of the modelled speed, respectively. The slope, s_v, together with the standard error, σ_{sv}, is estimated by the least squares method from sample data for each of the eight pre/post tests, which comprise of pairs of $v_{reproduced}$ and $v_{presented}$. Similarly to the speed, the time-duration is modelled by

$$\tau_{modelled} = s_\tau \, \tau_{presented} + i_\tau \quad (4)$$

The slope, s_τ together with the standard error, $\sigma_{s\tau}$, are also estimated by the least squares method from sample data, which comprise of pairs of $\tau_{reproduced}$ and $\tau_{presented}$.

A slope is a representative measure of sensitivity from the viewpoint of systematic error: the larger the slope is, the higher the sensitivity is. The difference of the slope from the ideal value of 1 can be regarded as a systematic-error measure. On the other hand, a random error measure can be defined by the standard error of the estimated slope, σ_{sv} and $\sigma_{s\tau}$. In order to comprehensively combine both the systematic and random error, a secondary evaluation measure is, then, introduced, that is, a ratio of the estimated slope to the standard error, s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$: they are a kind of signal-to-noise ratios (SN ratios) and follow a t-distribution.

As for the angles, there is no significantly large systematic error in the reproduced angles although a little periodical error may be involved. Consequently, we did not examine the systematic error of the angular perception. While, for the random error, the difference between reproduced and the presented angle, $\theta_{presented}$, were evaluated as shown in Figure 8. That is,

$$\Delta\theta = \theta_{secant} - \theta_{presented} \quad (5)$$

Then, the standard deviation of $\Delta\theta$, $\sigma_{\Delta\theta}$, is employed as a random-error measure on angular perceptual sensitivity. These values s_v/σ_{sv}, $s_\tau/\sigma_{s\tau}$, and$\sigma_{\Delta\theta}$ were evaluated for all the pre-training sessions and the post-training sessions for each of the 1st to 8th training days.

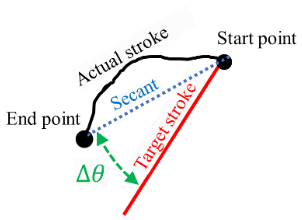


Figure 8. The secant of actual trajectory and the presented target trajectory were evaluated.

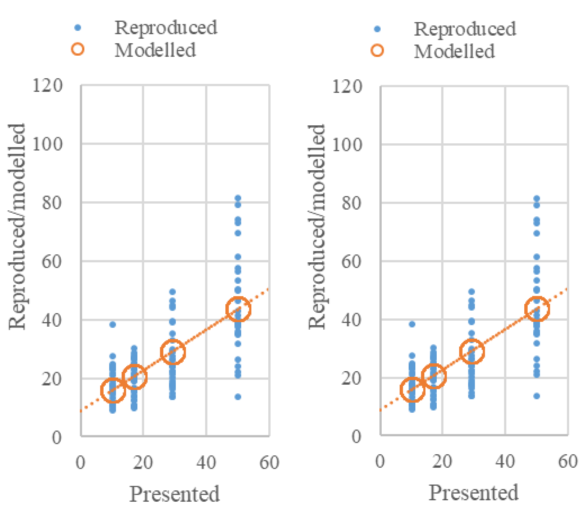
B. Experimental Results

1) Relationships between reproduced and presented speeds, time-durations, and angles

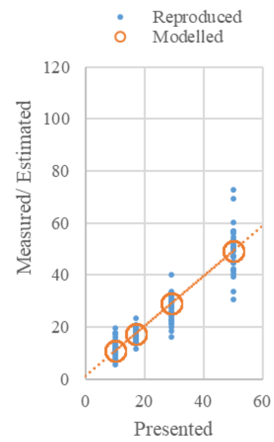
Some relationship of the measured and estimated values of the speeds, time-durations, and angles of the reproduced stroke to the presented values are shown in Figures 9, 10, and 11, respectively. In each of these figures, detailed results are shown in (a) the 1st-day pre-training session (b) the 1st-day post- training session (c) the 8th-day post- training session. From these figures, we can see the followings.

i. The reproduced speed, time-duration, and angle, were, as expected, almost proportional to the presented ones.

ii. The slopes of the speed and the time-duration, and the means in the angles represents systematic errors, and the dispersions represents the random errors. The slopes and the dispersion show much improvement after the 1st day training, and, also, another improvement throughout the eight-day training. That is, as for the reproduced speed and time-duration, the intercepts go to approach zero and the slopes become larger. As for the reproduced angles, mean errors for each of the presented angles 0 to 337.5 also go to approach zero. The dispersions for all the physical values, i.e., the speeds, the time-durations, and the angles, become narrow.

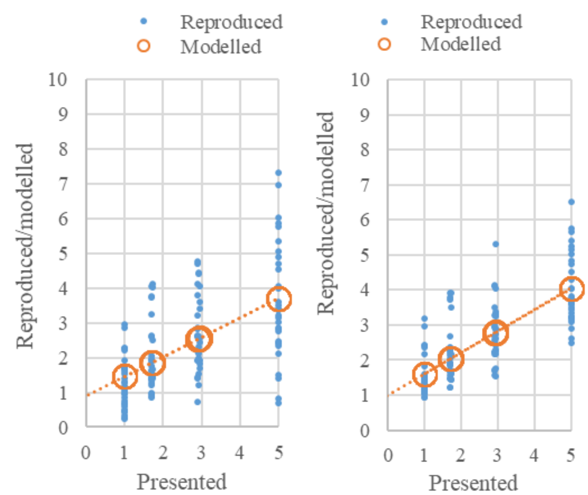


(a) 1st-day pre-training (b) 1st-day post- training

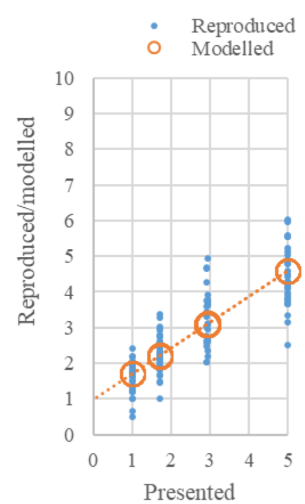


(c) 8th-day post- training

Figure 9. Some of the reproduced and modelled speeds.

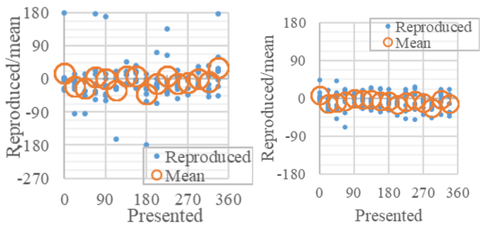


(a) 1st-day pre-training (b) 1st-day post- training

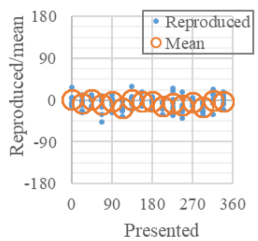


(c) 8th-day post- training

Figure 10. Some the reproduced and modelled time-durations.



(a) 1st-day pre-training (b) 1st-day post- training

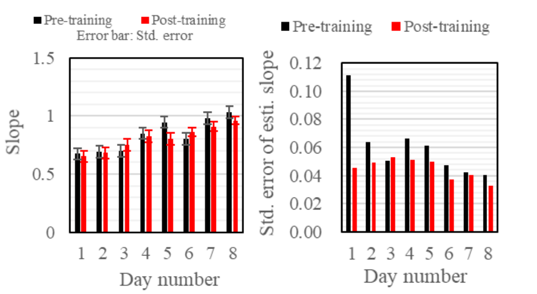


(c) 8th-day post- training

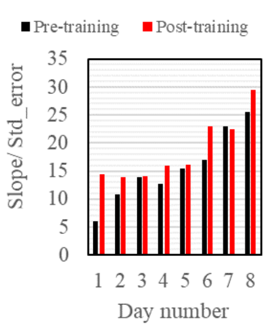
Figure 11. Some of the reproduced angle errors and their means.

2) *Speed slope, time-duration slope, and angular error mean*

The results of the slopes, s_v and s_τ, and the angular error mean, $\Delta\theta$, are shown in Figures 12, 13, and 14, respectively. In these figures, the estimated slopes, s_v and s_τ, are shown in Figures 12 (a) and 13 (a), and their standard errors, σ_{sv} and $\sigma_{s\tau}$. are shown in Figures 12 (b) and 13 (b). Furthermore, the ratio of the estimated slope to the standard error, s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$ are shown in Figures 12(c) and 13 (c). While, the means of $\Delta\theta$ are shown in Figure 14 (a), and their standard deviations are shown in Figure 14 (b).

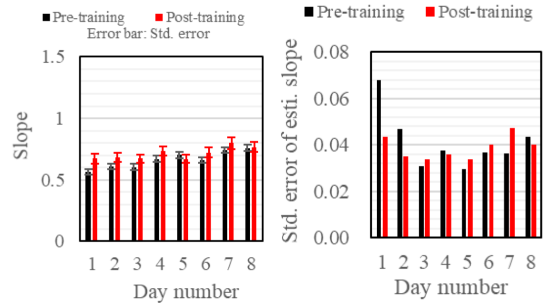


(a) Modelled slope (b) Standard error of the modelled slope

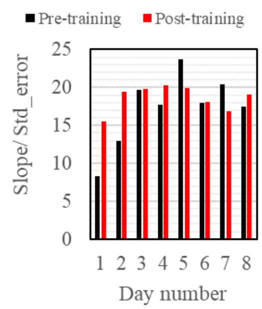


(c) Ratio of the modelled slope to its standard error

Figure 12. Evaluation values for the reproduced speeds.

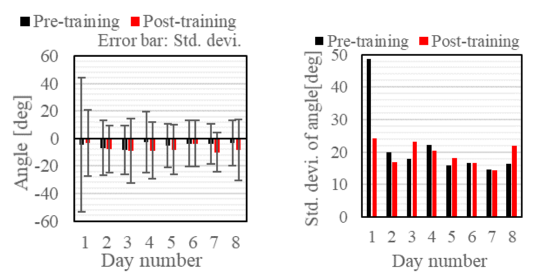


(a) Modelled slope (b) Standard error of the modelled slope



(c) Ratio of the modelled slope to its standard error

Figure 13. Evaluation values for the reproduced time-durations.



(a) Mean and standard deviation (b) Standard deviation

Figure 14. Evaluation values for the reproduced angles.

The three physical properties, i.e., s_v, s_τ, and $\Delta\theta$, were evaluated from the following two viewpoints.

i. Initial learning effect: the post-training test at the 1st training day (Post-1st) was compared to the pre-training test at the same 1st training day (Pre-1st). The comprehensive evaluation values were markedly improved for all the three physical properties. That is, s_v/σ_{sv} was improved from 6.04 (Pre-1st) to 14.4 (Post-1st), $s_\tau/\sigma_{s\tau}$ was 8.29 (Pre-1st) to 15.5 (Post-1st). Although each of s_v/σ_{sv} and s_v/σ_{sv} follows the *t*-distribution, the degree of freedom (DOF) for both, 79, are large enough to approximate the *t*-distribution by the standardized normal distribution. Then, we can approximate the distributions of the difference between s_v/σ_{sv} and s_v/σ_{sv} by the normal distribution (mean=0, variance=2). As a result, the differences of s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$ between Post-1st and Pre-1st were concluded significantly large with practically null significant probability. In addition, the standard deviation of $\Delta\theta$ was also improved from 48.6 to 24.1. Since the ratio of two variances follows the *F*-distribution (DOF: 79, 79), the value of 4.07 = $(48.6/24.1)^2$ concludes that the two variances were not equivalent at all. In short, the sensitivity of speed, time-duration, and angle after an initial learning were approximately two-times better than before.

ii. Overall learning effect: the post-training test at the final 8th training day (Post 8th) was compared to initial post-training test at the 1st training day (Post-1st). The comprehensive evaluation values were also markedly improved for all the three physical properties. That is, s_v/σ_{sv} was improved from 14.4 (Pre-1st) to 29.4 (Post-8th), $s_\tau/\sigma_{s\tau}$ was 15.5 (Post-1st) to 19 (Post-8th). Similarly to the initial learning effect, the differences of s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$ between Post-1st and Post-8th were concluded significantly large with practically null significant probability. In addition, the standard deviation of $\Delta\theta$ was also improved from 24.1 to 22.0. It confirms that the two variances were not equivalent. As a result, from the viewpoint of post-training test, it is confirmed that the sensitivity of speed, time-duration, and angle by Post-8th were also much better than those by Post-1st.

V. PRACTICAL EXPERIMENT

In this section, another perception-and-reproduction experiment on sime line-drawings composed of multiple strokes is described in order to show an effect in a practical application by exemplifying an improvement between before/after learning.

A. Experimental Method: Conditions and Procedures

As a practical experiment, the number of strokes was increased to seven or eight strokes including motions in the air: speeds and time-durations were selected from the experimental conditions are shown in Table II. The five subjects were the ones included in the eight subjects who had gone through the training.

The procedure was the same as that for testing described in Section III: Steps 1 and 2 were only once conducted for each stroke in a multi-stroke pattern, and no repetition was allowed.

TABLE II. FACTORS AND LEVELS IN PRACTICAL EXPERIMENT.

Factor	Level
Presentation strategy	After-recognition go strategy
Hand assignment	Slippage-perception with a non-dominant hand and stroke reproduction with a dominant hand (NDP&DR hand-assignment)
Presented line drawing stroke	Seven or eight strokes by uniform motion. The stroke patterns are not failliar to the subjects.
Speed [mm/s] × Time duration [s]	Pattern i and ii 4 levels: 10, 17, 29, 50 mm/s ×2.9 sec
	Pattern iii 4 levels: 29 mm/s ×2.1, 2.4, 2.9, 4.3, 4.8 sec

B. Experimental Results

Experimental results are shown in Figure 15. Although it leaves a little to be improved, the reproduced patterns after learning did much better than those before learning. Yet this is just an example, it clearly suggests a potential of the proposed learning protocol.

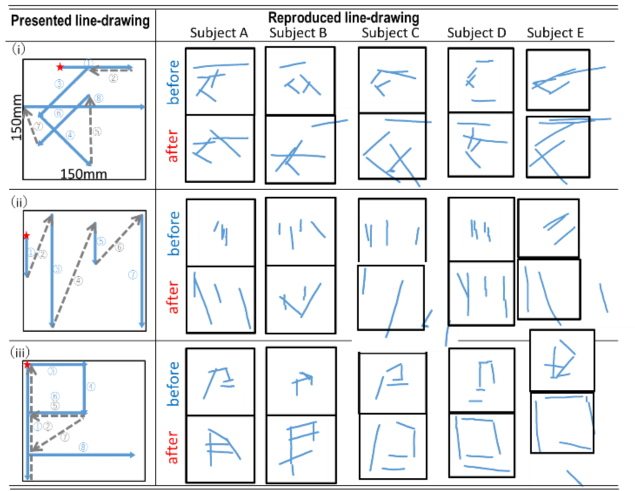


Figure 15. Experimental results of multi-stroke line drawing perception/reproduction before/after 8-day learning.

VI. CONCLUSION AND FUTURE WORK

A learning protocol for a finger tactile interface, i.e., an active-wheel-based finger-tactile (AWFT) interface was proposed. That is,

[Step 1] Aiming at a target hand-stroke, an AWFT-interface presents an initial slippage. While perceiving the initial slippage, a subject memorizes it as a translational motion, called an initial mental motion.

[Step 2] Recollecting the initial mental motion, the subject reproduces it as a hand-stroke.

[Step 3] The AWFT-interface presents a 2nd slippage corresponding to the subject-reproduced hand-stroke. Since the slippage is given by the motion made by subject's own self, the subject can improve their slippage sensitivity.

[Step 4] The AWFT interface again presents the initial slippage. Making sure of their initial mental motion, the subject can furthermore improve their slippage sensitivity.

As a result of a psychophysical experiment involving an intensive eight-day training on perceptual learning, users significantly improved their stroke perception-and-reproduction ability. The 1st day training doubled the perceptual sensitivities: the sensitivities with respect to the stroke speeds and time-durations were defined by the ratio of the estimated slope to its standard error—the slopes represent the proportional coefficient between the reproduced and presented speed and time-duration. While, the sensitivity with respect to the stroke angles was defined by the standard deviations of the angular errors.

Furthermore, the intensive eight-day training made the perceptual sensitivities significantly better than those after the 1st day training. In particular, the speed sensitivity was improved by two-times.

Thus, significant learning effects were confirmed from the viewpoint of the 1st day training and eight-day intensive training.

In the future, applicable area is expected to be extended for such strokes as curved and variable velocity strokes.

Acknowledgments

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Enabling People With Intellectual Disabilities to Participate in Design

An Immersive Strategy to Facilitate Long-term Participatory Design Using Social Workers as Proxies

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Abstract — **People with Intellectual Disabilities (ID) are often neglected in decision-making, and this paper introduces an immersive strategy for the inclusion of people with ID in Participatory Design (PD) processes by using the social workers as proxies. We present immersion as a methodological strategy on how social workers could use their knowledge of the end-users' capabilities to enable their participation in the design of technology. We draw on empirical data gathered through 180 workhours of voluntary fieldwork at an activity center in Norway for five months. Through immersion, we appropriated tools and techniques to the contextual concerns, and the results describe how the participation of people with ID enabled the social workers to co-explore concerns and ideas. This paper argues that the participation of people with ID can enable the social workers to explore their concerns through each user's means of communication, effectively giving people with ID a voice in the decision-making processes of technology design.**

Keywords — participatory design; intellectual disabilities; immersion; proxy designer; cognitive impairment.

I. INTRODUCTION

Participatory Design (PD) has long traditions of giving voices to different groups of overlooked or marginalized users by experimenting with ways to engage participants in co-design activities. This paper expands on previously reported results [1], and presents a long-term study of how we can include people with Intellectual Disabilities (ID) in the design processes of technology by addressing the overarching research question: "*how can we facilitate design with people with different intellectual capabilities using Participatory Design*?".

We report from a research project that involved collaboration with 82 participants and was conducted at an activity center in Norway. Our empirical work includes approximately 180 working hours of volunteer work, as well as the inclusion of participants in various ethnographic and design activities, over a period of five months. Our research project was structured into two phases: the first phase used an ethnographic approach where immersion was used as a strategy [1] to explore possibilities on how to include people with ID in future PD processes. This phase involved volunteer work and explorative workshops with both users and social workers at the activity center. Our empirical work generated a rich account of the daily activities, routines, and practices, on top of which we wanted to shape a PD process. The findings from this first phase included four themes governing future means of participation, and we operationalized these findings by shaping tools and techniques applied in the following phase. The second phase facilitated a design process where people with ID, along with their social workers, participated as co-designers. The goal of this second phase was to investigate whether the contextual knowledge gained during the first phase could inform a PD process where people with ID could participate in decision-making during the design of technology. The results and analysis of the participation from the second phase allowed us to reflect on the role of social workers as proxies for people with ID. Our findings demonstrate different ways the presence of social workers enabled dialogue in ways that supported non-traditional forms of communication, strengthened core principles of PD such as mutual learning, and allowed people with ID to engage in decision-making.

Based on our findings, we argue for the inclusion of social workers as proxies during PD processes involving people with ID. We point to concrete examples from our empirical context to demonstrate how including proxies have enabled new ways of engaging users that might otherwise not be included in PD activities. The findings presented in this paper offer both methodological and practical contribution to the PD community as well as other researchers engaging people with ID in design activities.

This paper is structured as follows. We begin by introducing three areas within PD literature in Section II that we find most relevant to our research project. Section III presents the framing of our study along with research objectives, the empirical context, and our research methodology. Sections IV-VI reflect the two main phases of our study by chronologically presenting methods, results, and findings. In Section VII, we return to our overarching research question to align our findings with ongoing discussions in related work. Our contributions and their relevance to the broader scope of discussion within the PD community end the paper in Section VIII.

II. RELATED WORK

In this study, we have conducted different ethnographic and design activities with people with varying degrees of agency to direct their own interests and needs. In the current discourse available, there is limited work that evaluates how people with ID can critically influence their own future regarding the involvement of technology. We have structured past related work after three, not mutually exclusive, means of achieving participation when collaborating with people with ID.

A. Enabling stakeholders through mutual learning

Two of the main principles in PD is *mutual learning* and *having a say* [2]. We begin by presenting literature that relates to how we can operationalize these principles: with a process supporting the informing of both researchers' and participants' understanding and imagination of possibilities.

Redhead and Brereton [3] explain how short-term methods as a means to engage in design can be ineffective for communities of people. They argue that the researchers' presence and activities are inherently academic, and might be too distant from the empirical context to understand and support local practice and interaction. Their suggestion on how to approach this challenge involves shifting from short-term to long-term commitment. A similar point is also raised by Maraveji et al. [4].

A common denominator in studies about people with cognitive impairments is the need for highly contextualized understandings of the participants and their challenges and capabilities [5]–[7]. As Holone & Herstad suggest, working with kids with disabilities requires more time to get to a "starting line" where the design process can begin [7]. Blomberg & Karasti present an important perspective on ethnography in PD as a means of "channeling access" to the context [8]. Holone & Herstad also stress the importance of starting the design in the practice of users [7].

B. Expanding the space with tools and techniques

The PD literature extensively covers the principle of *co-realization* [2], i.e., applying different tools and techniques, and how they extend spaces for both understanding possibilities and supporting co-creation [9]–[11].

The view of a method differs from the traditional view of a step-by-step recipe. It instead considers it to constitute general guidelines [2] that follow PD principles, which in combination with tools and techniques, stipulate how we can conduct design. Brandt et al. gather the essentials of what tools and techniques do into a framework of *telling, making,* and *enacting* [9]. They postulate that these principles are essential and happen in any situation where participation occurs. Hussain et al. elicit *telling* stories and explores possibilities using card sorting [12]. Galliers et al. utilize workshops where the end-users can enact current scenarios of use [13]. Kanstrup et al. propose a technique revolving around walking as a means to enable a sense of enacting and storytelling [14].

Tools and techniques can give people the possibility to "express themselves visually and verbally" [15, p. 1]. Focusing on early exploratory phases of design, Sanders & Stappers describe that "the focus is on using making activities for making sense of the future" and later "[..] the prototype is a vehicle for observation, reflection, interpretation, discussion, and expression." [11, p. 6]. In the case of a low-resolution prototype, which might itself be ambiguous, the collaborative act of *telling* or *enacting* stories of use can spur innovation [16]. These tools and techniques seek to be a bridge between the language gaps of designers and non-designers, where the physical objects can create visual languages [11], [15].

In the broader context of designing for and with people where limited cognitive or physical capabilities present different barriers to communication, offering several means of communication is crucial. Yekhlef & Essén argue for a phenomenological view and the body as a tool for innovation [17]. In the same manner as [18]–[20], they argue for a need to utilize already established practices to support the overall PD process.

C. Communicative challenges to participation

Previous studies also discuss the challenges of participation by proxy or mere presence as a means of tackling challenges that cognitive, physical, and organizational limitations present to participation. Brereton et al. argue that prototypes can be an important aspect in finding mechanisms that empower people with cognitive or sensory impairments and advocate alternative means of involving those in question [21]. Offering a similar perspective, Galliers et al. [13] and Dawe [22] suggest that words may not suffice if we want to empower users with cognitive or physical disorders.

Previous studies have also explored the use of proxies in the context of PD involving both adults and children with ID (e.g., [23] and [21]). Brereton et al. present the initial use of proxies as an important step towards realizing requirements, imagining possibilities, and ensuring successful inclusion of people with ID into the process of design after design [21]. There are other examples of successful inclusion of people with ID in specific phases of design, e.g., Dawe [22]. Putnam & Chong seek to gather information on software and technology use for people with autism through surveys directed at adult proxies, as well as some adults living with autism [24].

Francis et al. also characterize how challenges caused by highly individualized forms of communications among people with Asperger's and autism can be tackled with the correct management of the co-design process [5]. Brosnan et al. also reflect upon PD practice, challenges related to engaging different stakeholders, and also points to pitfalls such as overlooking the value of inclusion [25]. Finally, Hendriks et al. advocate the uniqueness of each co-design study for people with cognitive and sensory impairments and the importance of understanding the context and people in-depth when adjusting the methods applied [6]. One technique to approach the uniqueness of each situation can be the specific technique of probing [10], which seek "a more deliberate and steered process of facilitation, participation, reflection, delving for deeper layers in the past, making understanding explicit, discussing these and bridging visions, ideas and concepts for the future" [11, p. 8].

III. Research Design

To frame our study, we formulated one overarching research question along with two underlying research objectives. Our goal was to inquire into how we can adapt the design process to better suit the needs and desires of people with ID. To address our two research objectives, we organized our empirical work in two corresponding phases, namely Phase 1 and Phase 2.

A. *Overarching research question and research objectives*

Our overarching research question was "*how can we facilitate design with people with different intellectual capabilities using Participatory Design*?". To address this research question, we outlined two research objectives:

1. To present a rich account that can provide implications for how to intertwine contextual needs into a PD process.

2. To demonstrate how a PD process could be adapted to the contextual needs of the activity center by carrying out the initial stages of the long-term process.

Phase 1 utilized an ethnographic methodology in combination with PD to explore potentials for facilitating design with people with ID. Phase 2 applied the knowledge gained during Phase 1 to contextualize and adapt a PD process that prolonged the exploration of opportunities for participation.

B. *Empirical context*

The empirical context of our study is an activity center located in Norway with services offered to approximately 40 people with ID. Their ages range from 22-70 years with non-significant differences in gender distribution. The impairments range from mild to profound mental capabilities but also extend to physical challenges as people may have bodily configurations that also complicate autonomous functioning. To support each person's cognitive and physical capabilities, their everyday activities are individually tailored and organized to maximize the sense of autonomy. For some people, this requires one-on-one assistance from social workers, while others can work in groups or even without any direct assistance. The social workers' background ranges from non-related or lacking a higher education to domain-specific competencies such as social workers, social educators, teachers, and ergotherapists.

The everyday dialogue between the people and their social workers is highly contextualized, e.g., through the use of visual aids (see Figure 1). Certain users can only communicate when using a limited and tailored vocabulary. However, the social workers rely on many forms of non-verbal communication, most of which are directly tied to the context, e.g., objects, places, activities, and routines found at the activity center.

Figure 1. Illustrations were used as a visual aid offering an alternative form of communication

Examples of such non-verbal forms of communication include icons, signs, physical gestures, and photographs. The activity center offers a wide range of both educational and recreational activities for the users such as therapeutic activities (e.g., music and light therapy), ludic activities (e.g., games and audiobooks), creative activities (e.g., painting and sewing), and physical actives (e.g., swimming and field trips).

The employees of the activity center are hereafter defined as social workers, understood in its broadest definition: "social work remains a service focused on disadvantaged and marginalized individuals and group" [26, p. 1]. In the context of the activity center, a social worker carries out work that is essential for the day-to-day functioning of adults with physical or intellectual disabilities, who otherwise lack the capabilities to direct their cognitive or physical person in any given situation. Directly translated from Norwegian, employees hold positions of 'environmental therapist' or 'environmental worker', which quite aptly explains their role: to facilitate an environment for people with different capabilities to thrive. Similarly, we apply the word *user* throughout the paper to describe people with ID using the facilities or services offered at the activity center. This notion is derived from people being users of healthcare systems or services [27]. Linguistically, it also represents a neutral word that allows the social workers to talk about the people with ID without stigmatizing or revealing specific details about the users in everyday communication. We attempt to distinguish this notion from users in a design process by describing the latter as end-users rather than users.

C. Research Methodology

The overarching methodological approach of this study follows the traditions of Participatory Design (PD) – a worldview that emphasizes the inclusion of the people who will eventually use the technology in the design process as equal co-designers [3]. Central principles of PD include mutual learning, co-construction, and having a say [2], and our approach attempts to create a space for engagement supporting these principles while simultaneously allowing us to design technologies for and with users with ID. One of the central challenges in our long-term PD process is to support co-creation and autonomy without necessarily demanding participation from users in both phases and all activities. As mentioned, the study was split into two phases, hereafter referred to as *Phase 1* and *Phase 2*. An overview of the key characteristics of the two phases is outlined in Table I.

Phase 1 relies on immersion as a strategy to build up enough contextual knowledge about the users, their lives, and everyday activities, to represent their voices in activities where they are not interested in, or unable to, participate themselves. We see the PD process as a use-oriented design cycle that requires familiarity with both the real-life problem situation and the practice [2] before moving to the elicitation of needs and requirement descriptions. One of the arguments we present in this paper is that immersion constitutes a necessary component in studies involving proxy designers engaged on behalf of users with an ID, especially when representing the users' voices in the design of technology intended to support them with their everyday goals and activities.

Immersion, in our context, draws on ethnographic traditions and practices. More precisely, we align our view on immersion with Crang and Cook's intersubjective perspective [28, p. 37]: *"participant observation should not be to separate its 'subjective and 'objective components, but to talk about it as a means of developing intersubjective understandings between the researcher and researched"*. We position ourselves as such due to the embedded emphasis on mutual learning in PD [29], and we argue that the contextual knowledge gained through immersion during the earlier stages of a long-term PD process is vital to the facilitation of later design activities. Thus, the results, findings, and discussions of this paper revolve around how non-users engaged as proxy designers can better connect with the everyday world of the users and actively change it and create new knowledge through immersive participation.

The long-term commitment of the study was conducted every week, where one of the authors of this paper worked on a volunteer basis at the activity center. The volunteer work included working closely with the proxies and the users of the activity center, engaging in everyday activities, learning about their different means of communication and lives in general. The nature of the communicational difficulties experienced by the users suggested that the proxies were very important in bridging an apparent gap of knowledge that was required to have meaningful interactions with some of the users. On an everyday basis, the employees collaborate to bridge their differences in knowledge and ask each other questions about how to perform specific tasks or activities. The social workers are proxies to the users because they continuously try to mediate their wants and needs and facilitate for a workday that carries meaning to the users in some way.

TABLE I. OVERVIEW OF THE KEY CHARACTERISTICS IN THE TWO PHASES

Key characteristics	**Phase 1 – Exploration**	**Phase 2 – Facilitation**
Methodology	Ethnographically immersive/infused PD	Participatory Design
Focus	Exploring possibilities for conducting design with people with ID	Investigating assumptions about possibilities for the participation of people with ID
Methods	Participatory inquiry	Generative workshops, interviews and group discussions
In-situ workhours	Approximately 100 workhours	Approximately 80 workhours
Participation	Volunteer work and explorative workshops.	Including people with ID into design making by utilizing proxies' knowledge about capabilities
Participants	34 people with ID 18 social workers 2 researchers 2 fellow researchers	8 people with ID 17 social workers 1 manager
Results	Ethnographic account	Outline of participation
Main findings	Four themes governing possible future means of genuine participation	Two themes describing how social workers facilitated user engagement

Phase 2 is an attempt at operationalizing the learning outcomes from Phase 1 by utilizing the familiarity with the real-life situations, practices, and people to shape a PD process that seeks to include people with ID into the design-making. Facilitating dialogue when engaging participants with reduced communicative capabilities, which is often the case when working with people with ID, is one of the challenges addressed by previous studies, e.g., [13], [21], [22]. In their review, Börjesson et al. [30] found that children with ID are relatively seldom included in the design, and when they are, they have a passive role. They found that children with ID were only included during the initial inquiries and the later testing, never during design.

In Phase 2, we utilized some central concepts of PD: *telling, making and enacting* by Brandt et al. [9], which enables the participants to tell stories about what they make and enact scenarios of use. Sanders & Stappers [11, p. 6] say "the focus is on using making activities for making sense of the future" and that "[…] prototypes is a vehicle for observation, reflection, interpretation, discussion, and expression." [11, p. 6]. Brandt et al. [9] express that innovation can occur when combining low-resolution prototypes with the collaborative act of telling stories or enacting possible scenarios of use.

Visser et al. [10] created a set of generative toolkits that, among other, seeks "a more deliberate and steered process of facilitation, participation, reflection, delving for deeper layers in the past, making understanding explicit, discussing these, and bridging visions, ideas and concepts [scenarios] for the future." [11, p. 8]. The three techniques used in *Phase 2* are *sensitization, collaging, and drawing* inspired by [10]. Between designers and non-designers, there is a language gap that these methods seek to bridge by using physical objects to create a visual language supporting participants in an exploration and expression of possible futures [11], [15]. We align our view with the concepts of *having a say*, creating opportunities for *mutual learning,* and *co-create* the future. In combination, these techniques seek to give people a language to tell, make, and enact their own futures.

IV. Phase 1 – Exploration

The first phase emphasized generating contextual knowledge at the activity center that could later scaffold a PD process with the users. The data was gathered through six research methods involving 56 participants, including people with ID, their social workers, one manager, and fellow researchers. Table II presents an overview of the six research methods and the participants involved in each activity.

TABLE II. OVERVIEW OF THE RESEARCH METHODS

#	Research method	Participants
A	Participatory inquiry	30 users and 15 social workers
B	Contextual observation	Researcher
C	Diary journaling	Researcher
D	Explorative workshop I	2 researchers and 1 design expert
E	Interviews	Manager
F	Explorative workshop II	6 social workers

A. Phase 1 – Research Methods

1) Participatory inquiry

One of the authors of this paper immersed himself into the context by taking on the role of a volunteer social worker, receiving formal training and introduction similar to the training provided to all other social workers. The data presented here originates from the first four months of work, which equals approximately 100 working hours. The goal of this immersive activity was to gain knowledge through a first-hand experience of the context and the users we are designing for and with in the second phase of our study. The methods of inquiry included observations and shadowing of social workers and users during everyday activities, their interaction with technology, as well as their means of communication. The data produced from this activity consisted of notes, photographs, and mind maps.

2) Contextual observation

The purpose of the observation was to capture important contextual concerns in a medium suited for later design activities where the participants might not possess verbal communication skills. As such, the data was documented in the form of photographs. 50 suitable photographs that described important contextual relationships related to everyday activities, interaction between people, and technology were selected. Most of these photographs were taken after working hours to ensure that the authors' presence did not disrupt or interfere with the users' activities. We observed several relevant contextual concerns that included technologies (e.g., audio systems, massage chairs, and light projectors), objects used in activities (e.g., instruments, games, and drawings), places of interest (e.g., sensory rooms, resting places, and creative spaces), and different workshops (e.g., woodworking workshop, pottery and textile). Figure 2 depicts some specific examples: the top left image shows a knitting station; the top right image shows the multipurpose workshop; the bottom left shows the ball pit; the bottom right shows some of the paper shredders.

Figure 2. Examples of contextual concerns

3) Diary journaling

After each full day of volunteer work, an entry was written in an elicitation diary describing the activities and communication challenges encountered. Important events, major issues, and concrete examples of situations requiring contextual insight constituted the main content of the diary. Similar to the contextual observation, most of the diary entries were produced after working hours or in the absence of users as the goal was to allow everyday activities to progress as normal despite being the subject of investigation. Throughout the first four months, 18 journal entries were written down, ranging from a couple of sentences to several pages.

4) Explorative workshop I

To explore design opportunities in the context of technology intended to support users with ID in their everyday activities, we engaged two fellow researchers in an explorative workshop. During the workshop, we presented data from the previous activities such as photographs, mind maps, and transcribed interviews as the basis for a discussion of how we can facilitate future design activities in our PD process. Furthermore, both researchers conducted an individual objective coding on the same data set, which later served as the basis for a reflection of the insight gained through immersion and how contextual knowledge directly affected our interpretation of the same set of data.

5) Interviews

An important part of the immersive approach was facilitating easier access to both contextual and domain knowledge, which included in-depth details about the capabilities of each person using the activity center. One of the main sources of information was ten semi-structured interviews with the manager of the activity center. The interviews revolved around practical and organizational issues that were relevant to our facilitation of a PD process, including both the users and their social workers. These interviews revealed opportunities and limitations for participation, e.g., insight into the working schedule of the social workers, as well as suggestions on suitable social workers who could fit the role of participating proxy designers in later stages of our PD process. Each interview lasted between 30 to 60 minutes, and the interviews were scheduled throughout the first four months, depending on the manager's availability.

6) Explorative workshop II

The final activity in our initial phase of the PD process was a second explorative workshop conducted with six social workers at the activity center during a morning meeting. The goal of this workshop was to compare how the social workers as potential proxy designers understood the everyday activities and communication challenges found within their own work context with issues we had identified. We also used their in-depth knowledge of users and everyday activities to facilitate a group discussion on how to scaffold the PD process around existing routines and preferences to best support our underlying PD principles, i.e., mutual learning, co-construction, and having a say. Another result was the surfacing of what the social workers perceived as meaning makers for the users.

B. Phase 1 – Results

The data gathered through the six activities outlined in the last subsection consisted of diary entries, transcribed interviews, observation notes, discussion summaries, mind maps, individual data coding from workshops, and photographs. From the data, we identified two recurring topics that were common across all the activities and mentioned by all participants, both users and non-users, namely activity and communication. These two topics also embody most of the underlying issues that were discussed during the two exploratory workshops. As such, we used these two overarching topics to help us structure our analysis of whether immersion could contribute to more in-depth insight to help facilitate the future activities of our PD process.

1) Activity

As our empirical context was an activity center, there was an intrinsic emphasis on activities. Both the social workers employed at the activity center and the users rendering the services shared an activity-centric focus. Already during the first participatory inquiry, we registered that the social workers' training revolved heavily around daily routines and how different users engaged in activities. Concerning how to engage the social workers as proxy designers in our PD process, the manager who was interviewed explained that the availability of these social workers was highly related to their work schedule, which in turn revolved around activities. This point was also raised during the first exploratory workshop, where the participants believed it would be easiest for both the social workers and the users if the PD process was structured around activities.

From the users' perspective, we registered through the diary entries that most of their autonomy, as well as the sense of pride and accomplishment, were related to both the activity and the context in which it took place. One of the reasons for selecting activity as a common denominator was that users who engaged in activities experienced a multitude of personal reactions and rewarding sensations based on their particular capabilities and background. We also learned during the second exploratory workshop that participation in activities was itself an important catalyst for the users' sense of mastery. In some cases, the act of carrying out an activity was of greater importance to the user than the purpose or end-goal of the activity. The photographs from the contextual observation complemented this point by revealing that most of the equipment present at the activity center was not intended at problem-solving, but rather as means to enable engagement in activities without necessarily having a fixed end-goal. Finally, we made multiple observations of how successful participation depended on the activity's ability to acknowledge the user's vulnerability, e.g., sudden urges to use bathroom facilities.

2) Communication

One of the main challenges when working for and with people with ID is facilitating communication. Previous studies have discussed the need for compensating strategies, e.g., [23]. This is especially important to our PD process and the emphasis on mutual learning. In our empirical context, we found multiple examples of how the activity center compensated for the lack of verbal communication skills. One such example was the labeling of the shelf shown in Figure 1, where photographs rather than text communicated different activities.

Another prominent example was the users' individual daily diaries where the social workers registered all entries and then communicated a summary back to the user. In later situations, the diary itself became a means of non-verbal between the user and the social worker. The social worker who participated in the second exploratory workshop also described how being seen and heard was vital to the users' motivation. Most forms of communication were self-developed and internalized by the different users and the contextual activity at hand. As such, one of the contextual insights gained through the participatory inquiry and the elicitation diary entries was instances of different, but highly specific, combinations of gestures and speech employed by the users to communicate with their social workers. To facilitate a proper dialogue where the users can communicate choices and selections, understanding these varying forms of communication is a necessity for all parties. In the most extreme cases that we observed, some users relied entirely on the social workers' ability to interpret their language, or lack thereof, as well as the social workers' ability to reduce the dialogue to questions that the user could answer with a simple yes or no by using their bodies.

C. Phase 1 – Analysis

We identified two recurring topics in our data, namely activity and communication, and we wanted to use these two topics to structure our analysis. While the emphasis on these two topics emerged from the empirical data itself, they align well with the goal of our overarching PD process, i.e., designing technology that supports people with ID in their everyday activities. The embedded nature of creating spaces for co-construction and mutual learning in PD also depends on our ability to facilitate communication between participants. As such, we used these two topics to structure our analysis. Figure 3 illustrates how the analysis included multiple people and different types of data.

1) Inter-rater reliability analysis

During the first analysis, we wanted to examine to what degree our immersion strategy actually provided contextual insight. The individual coding of the same data set performed by the two researchers in the first exploratory workshop yielded a total of 64 overlapping first-order codes shared by the two coders. The data included in this analysis consisted of photographs, observation notes, elicitation diary entries, and documents from the activity center. A thorough description of the analysis procedure we followed has been reported in [1].

Figure 3. Examples of raw data (top row) used in the analysis (bottom row)

We compared these two sets of individual codes to examine how a researcher without contextual knowledge of the users and their everyday lives identified opportunities and challenges relatively compared to the author who had gained contextual knowledge through 100 hours of in-situ volunteer work during the participatory inquiry. More precisely, we wanted to use the inter-rater reliability between these two coders to examine whether the researcher without any contextual knowledge rated each code similar to the researcher who had immersed himself into the context. To study the consensus, both coders individually labeled each of the 64 codes as either activity or communication. We then used Cohen's kappa to determine the exact level of agreement between the two coders. The result of the cross-tabulation is outlined in Table III, where Researcher A represents the immersed author, while Researcher B represents the researcher without any contextual knowledge.

TABLE III. ANALYSIS OF INTER-RATER RELIABILITY

		Researcher B		
		Communication	Activity	Total
Researcher A	Communication	21	7	28
	Activity	12	24	36
	Total	33	31	64

From the table, we can see that both researchers divided the number of codes between the two topics fairly equally: Researcher A labeled 28 codes as communication and 36 codes as activity, while Researcher B labeled 33 codes as communication and 36 codes as activity. However, there were large discrepancies in which codes that were labeled under each topic. The coders agreed on 21 of the 64 codes (32.8 %) as examples of communication and 24 of the 64 (37.5 %) as examples of activity. However, the level of inter-rater reliability was still only moderate, $\kappa = .409$ (95 % CI, .189 to .629), $p < .001$. As such, we see that the two researchers had a different understanding of the latent meaning behind similarly identified codes in the same data set.

2) Thematic analysis

During the second analysis, we conducted an inductive thematic analysis of all the data gathered to elicit themes related to our two topics activity and communication. The goal was to use the themes to summarize and exemplify the type of contextual knowledge that was accessible through our emphasis on immersive participation. To structure our inductive thematic analysis, we followed the procedure presented by Braun & Clarke [31] and used the two topics activity and communication as the overarching topics to tie together the different emerging themes. The preparation consisted of transcribing relevant audio recordings from workshops, annotating photographs, and a systematic structuring of all elicitation diary entries and notes from the participatory inquiry. We categorized the data into 40 first-level codes that constituted the lowest level of patterned responses and opinions. The codes were collated into 15 categories that were organized as four main themes. We ended our thematic analysis by mapping out the relationships between the different categories and themes, and by relating them to our overarching analytic topics activity and communication. Figure 4 illustrates the categories and themes identified. We omitted the 40 first-level codes as they were all collated into the 15 categories outlined in the figure.

D. Phase 1 – Findings

1) Contextual insight gained through immersion

Table IV presents a summary of the four themes identified in the data during the thematic analysis: meaning, practice, choices, and routines. These four themes represent the type of contextual insight gained through our immersive PD approach; the two former themes relate to activity as an overarching topic, while the two latter relate to communication. The table also lists the source methods for each of the themes, along with key quotes or observations. The four identified themes are examples of higher-order issues that we have separated to highlight the different types of contextual insight gained through immersion, as well as to demonstrate the variety of relevant considerations. As such, the themes are not four separate and independent examples of insight, but rather four overarching themes that represent a set of overlapping and intertwined factors.

Meaning outlines an understanding of the meaning bearers for the users. P*ractice* describes the context and the various kinds of work and activities carried out at the activity center. *Choice* describes the challenges the users and employees face during decision-making, as well as how they are resolved in situations involving different cognitive capabilities. *Routine* defines how we can understand the role and implications of the daily routines within the everyday lives of the users.

2) The distribution of a difference in understanding

The four themes and the underlying categories from the thematic analysis were also used to assess whether the differences in interpretation between researchers with and without contextual knowledge pertained to specific themes or created divergence across all themes. The 64 codes used to assess the level of agreement between the coders in the inter-rater reliability were compared to the 40 first-order codes used to structure the thematic analysis, and the differences were visualized. Figure 4 combines the four themes with the analysis of inter-rater reliability to demonstrate how the differences in understanding of contextual factors were distributed across all themes and underlying categories. The white circles indicate a similar understanding for all underlying codes; the striped-colored circles indicate disagreements in only some of the underlying codes; and the grey circles indicate disagreements in all underlying codes, i.e., the whole category itself.

As we can see in Figure 4, the differences between the two coders were distributed across all four themes, as well as 11 of the 15 underlying categories. For instance, the two coders interpreted the whole theme of *routine* very differently, including all underlying categories. In other cases, the differences in interpretation of first-order codes did not propagate as the clusters of codes were identified and collated. One such example would be *profession*, where only one out of several codes was read differently without affecting the affiliated theme. As such, the contextual knowledge gained through immersion was not limited to certain aspects of activity or communication but pertained to most categories branching out of the four themes. *Stimuli* is another example of how contextual knowledge created a divergence between the coders. For the researcher with contextual knowledge, this code was considered an in-vivo code, referring to a specific activity, while the researcher without contextual knowledge understood it as a matter of communication rather than activity. We saw similar differences with *physical challenges*; the researcher with contextual knowledge referred to communication challenges with this code as most users relied on bodily gestures to communicate, while the researcher without contextual knowledge saw this as a challenge related to participation

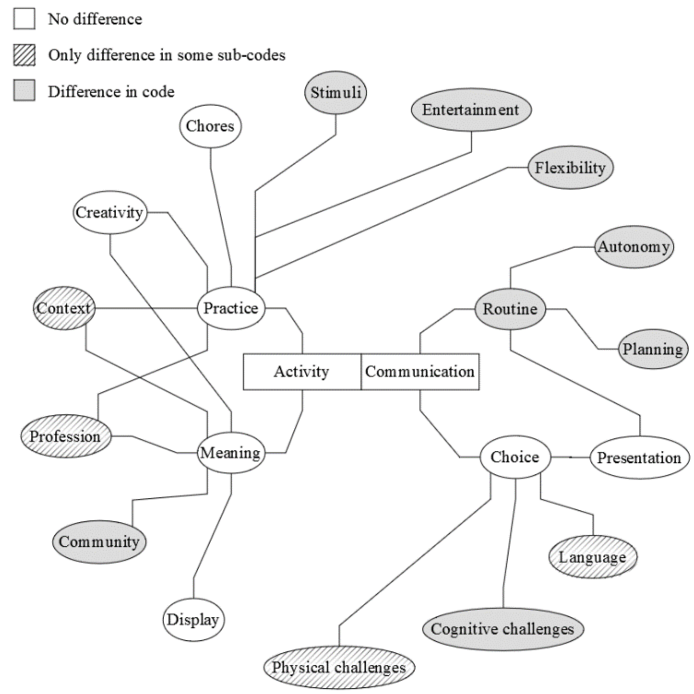

Figure 4. Distribution of difference in coding between the two researchers

TABLE IV. OVERVIEW OF THE FOUR THEMES AND MAIN FINDINGS

Theme	Main findings	Source	Key observations and quotes
Meaning *(Activity)*	• Meaning emerges through the context in which the activities take place. • The company of the social worker can affect the way in which meaning emerges.	[A], [C], [F]	Users have individually tailored activities and contexts to situate specific kinds of meaning *"Examples of meaning bearer are social relations, safety, predictability, well-being, change of environment, learning and acknowledgment."* (social worker, [F])
Practice *(Activity)*	• The practice involved in activities varies between users. • Activities need to be flexible regarding duration.	[A], [C], [E]	*"Some activities require 1-on-1 assistance depending on the individuals involved and the context in which it is carried out."* (diary entry, [C]) *"During the first day, I had to end an activity with a user because I was requested to help with something else"* (diary entry, [C])
Choices *(Communication)*	• Presentation of choices must be tailored to both the user and the context. • Limited language and cognition skills inhibit the presentation of choices.	[A], [B], [C]	*"The user was presented with two alternatives, which I later discovered was a rather restricted choice considering the user's capabilities"* (field note, [A]) Representations of choices often require non-verbal forms of communication (see Figure 1, [B])
Routines *(Communication)*	• Structure and daily routines affect the users' ability to participate. • Routines promote autonomy by facilitating learning over time.	[A], [C], [F]	*"For some users, it is a crisis to have a day off as it breaks routines"* (social worker, [F]) *"One user was frustrated when I communicated that I had to leave early because it disturbed some of the users' routines"* (diary entry, [C])

opportunities in activities.

We argue that this distribution of the difference in understanding creates highly different outlooks for the facilitation of an inclusive and tailored PD process involving users with ID and their social workers as proxy designers.

V. CONVERGING ON INTERMEDIATE LEARNING OUTCOMES

This section links the two phases. As reported in [1], we summarized our findings from Phase 1 as three broader learning outcomes to guide future work: (1) build on established forms of mutual learning; (2) facilitate for social workers as proxies; (3) organize long-term.

During the planning of Phase 2, the three learning outcomes directed the overarching methodological necessities, while the contextual knowledge about the activity center and its users directed pragmatic action-oriented planning of tools and techniques. One requirement that emerged from Phase 1 was that the social workers still needed to be able to fulfill their roles as social workers. As a result, the process required that the users were engaged in design activities as though any other activity at the center. One of the main challenges would thus be to correctly manage the design process so that the social workers were enabled to both facilitate the inclusion of users, as well as conducting design workshops. As such, the social workers had to engage in two parallel design sessions: they needed to facilitate their own participation while simultaneously facilitating for the users to engage in the design process.

In Phase 1, we explored the social workers' potential for working *with* the capabilities of the users to facilitate everyday activities. This is present in the understanding of the themes *choice* and *routines*, which mainly reflects the supporting role of the social workers in day-to-day communication. We also explored *practice* and how *meaning* emerged. The four themes, in combination with the three learning outcomes, created a baseline for making six action-oriented guidelines to the upcoming PD process in Phase 2. The three former aimed at enabling the users' participation, while the three latter focused on proxies' participation where established forms of mutual learning and general knowledge about the practice were utilized:

1. Include a social component.
2. Appear similar to existing activities.
3. Offer flexibility through contextual adaption per the users' needs.
4. Introduce social workers to their roles.
5. Utilize tools and techniques that enable reflection on the role of participants.
6. Utilize tools and techniques that enable reflection on the role of facilitator for user participation.

These guidelines helped us plan Phase 2 by facilitating participation for both the users and proxies. We utilized the guidelines to help us shape the use of tools and techniques applicable in future PD generative sessions. In Figure 5, we illustrate this move between the two phases. The use of social workers as proxies in the design process was vital in enabling the users to participate, hence the vertical orange arrow between users and proxies.

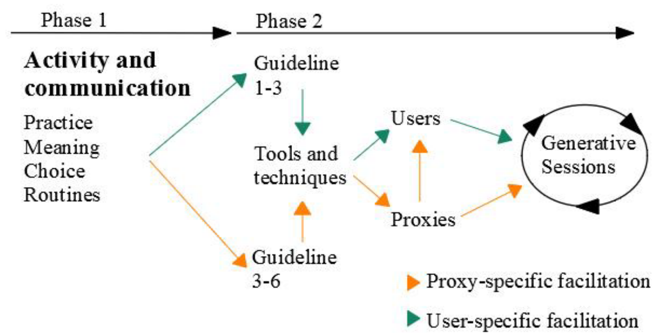

Figure 5. Moving between the two phases using the six guidelines

VI. PHASE 2 – FACILITATION

With the help of the six guidelines, we engaged 20 participants in three generative workshops where tools and techniques were informed by the contextual knowledge gained during Phase 1. To help us organize and reflect upon the workshops, we conducted an initial preliminary interview with the manager, as well as one concluding set of participant interviews. In total, Phase 2 included 26 participants and involved approximately 80 hours of in-situ presence. Table V outlines the main components of Phase 2.

TABLE V. OVERVIEW OF RESEARCH METHODS

#	Research method	Techniques	Participants
A	Preliminary interview	1on1 interview	Manager
B	Three generative workshops	Polaroid, collaging, and drawing.	12 social workers and 8 users
C	Participant interview	Group and single	5 social workers

Initiating a new dialogue between researcher and participants was carried out by targeting some of the already established routines and tools to organize meetings. We also had to spend time in context to recruit and introduce those who were unable to join. The main objective of the introduction was to sensitize the social workers to their role as facilitators and participants. A secondary motivation was to create a common goal, as emphasized by [12] and [13].

A. Research Methods

1) Preliminary Interview

We conducted a preliminary interview with the manager that guided most of the practical concerns of conducting our long-term PD process. One specific issue we wanted to overcome was the challenge of social workers participating without being aware of the goal and progress. Tailoring the design activities around their work schedules allowed us to maximize their opportunities for participation and mutual learning throughout the duration of the whole PD process. In addition, avoiding scheduling conflicts would help us circumvent fragmented participation from the social workers where we could risk them rejecting participation due to short burst facilitation [3]. It was also helpful to anchor a shared vision with the manager on how and what we wanted to achieve with the design process.

2) Three Generative Workshops

We utilized the three techniques outlined by Visser et al. [10]: sensitization, collaging, and drawing. There is a limitless number of tools and techniques available [9], as exemplified by [10, 12, 15, 32]. Generative techniques utilize tools that ideally are fitted to suit the context. Brandt et al. describe the role of such tools: "Today the generative tools describe a design language ideally suited by non-designers. It is a full palette of predominantly visual components that enable participants to explore and express playful landscapes of past, present and future experiences." [9, p. 159]. The generative workshops were organized in common spaces within the activity center, familiar to both the users and their social workers (see Figure 6).

Figure 6. Examples of shared spaces where the workshops were organized

a) Sensitization

"In the sensitizing phase, participants perform exercises designed to let them think about past experiences, and make them 'reflective practitioners (Schön, 1983) of their present experience" [10, p. 126]. The goal of the sensitization was to introduce the social workers to their roles as both proxies and facilitators for the inclusion of users. Attempting to create an engaging workshop, we crafted a toolkit, composed of different creative tools (Figure 7), a small booklet with directions and questions as well as an Instax Polaroid camera. We sought to utilize tools in completing simple tasks that both introduced the proxies to their roles, and also let them reflect on those.

The sensitization was conducted by handing out the toolkit with a 20-minute introduction and discussion, as well as a small instructional chart answering questions they might have. We then left the toolkit at the center and did follow-up interviews in the coming days. Three introductory sessions were conducted with six participants over two workdays.

Figure 7. Sensitization toolkit

b) Picture Collaging

Similarly to [33], the recruiting of participants depended on recruiting for single sessions, as the activities needed to be timed according to schedules, existing practice, and depended on the day-to-day health, wellbeing, and needs of the users.

For the collaging session, one of the main goals was to co-create something intriguing for different people. The toolkit crafted consisted mainly of imagery targeted towards specific individuals as well as more generic imagery. The toolkit consisted of around 120 images, 40 words, and a large toolkit of creative artifacts (see Figure 8).

Figure 8. A large toolkit of creative artifacts

The images were chosen in several themes related to the design of technology, more specifically technologic possibilities, interfaces, emotions, contextual, accessibility, and individual and diverse iconography. The sessions were conducted by handing out the different tools, then instructing and continually guiding the participants through the creative process. A total of five sessions were organized with 20 participants in a span of eight workdays.

c) Drawing

The drawing workshop was initially intended to be as extensive as the collaging workshop. However, due to time constraints, as well as an extended amount of time spent conducting the collaging session, only one participant conducted the drawing session. In [10], the drawing session is integrated into the collaging, but we chose to separate them to accommodate the experienced need for flexibility in conducting any activity.

3) Participant Interviews

The participant interviews were conducted to follow up on the generative sessions. The reason for conducting follow-up interviews was two-fold. First, they were conducted to make sure the social workers did not dismiss or reject the value of the workshops to innovate and design future solutions. Second, it was a reaction to the social workers not always being able to finish the sessions. We saw this as an opportunity for the social workers to discuss their thoughts surrounding the themes explored, even if they were unable to finish their participation.

B. Phase 2 – Results and Analysis

The data gathered through the three different activities in Phase 2 consisted of transcribed interviews, observation notes, discussion summaries, individual coding from workshops, photographs, resulting workshop artifacts, and Polaroid diaries. The analysis involved a coding process around two themes. First, *social workers' facilitation* emerged as a cluster of all concerns related to whether the social workers had been able to implement the design activities of workshops. This also included its tools and techniques, and to what degree they could facilitate the inclusion of people with ID into the activities. Second, *social workers' exploration,* gathered all observations of how the social workers utilized the presence and participation of the users to enact and explore ideas and assumptions about the capabilities of the users.

1) Results

A total of ten different generative sessions were conducted, along with seven follow-up interviews held in the span of ten workdays. 12 social workers actively participated in the generative workshops in collaboration with eight users. Without presuming to know the people with ID's health conditions, we consider user participants to be within profound to severe ID [34]. The users' age ranged from circa 35 to 60 years old with physical disabilities ranging from profound to negligible.

a) Social workers' facilitation

Throughout the generative workshops, the social workers included the users in the workshops as active participants, using the different generative tools as well as their knowledge about users' general capabilities. In discussions and interviews, the social workers focused almost exclusively on communicational aspects on how to include the users into the workshops, emphasizing their physical, cognitive, and language capabilities.

The social workers often described how they accommodated the user's cognitive capabilities. They also reflected on how to present choices. One such example was during the early stages, where one social worker reflected on asking leading questions and changing the wording after conducting the sensitization. In a group discussion following the sensitization, two social workers discussed how they had to change the wording of the sensitization kit.

In another workshop, two social workers used the morning meetings and introductory talks to discuss the possibilities for one particular user's participation. This user had had "a bad week", and the social workers who had been working with the user previously were apprehensive about how they could adequately include the user. In the introductory talks, one social worker explained and reflected on this user's need for social interaction to generate meaning. When they later worked with facilitating the user's participation, they specifically focused on how to make the activity social, using both the tools available and their knowledge of the user's capabilities. While they initially were apprehensive to include the user, they managed to co-ideate a paper prototype for a planning and communication tool.

b) Social workers' exploration

During the three generative sessions, we discovered how the social workers developed their understanding of the design problem through the users' participation in the same workshops. One main reason was that the social workers could exploit the presence of the users to explore assumptions about their capabilities and help navigate their own design ideas. To achieve this variant of mutual learning, the social workers would often use pre-existing contextual tools, the toolkits, or even co-crafted new tools to explore.

The social workers would also use the presence of the users to scaffold their understanding of how the users made choices and understood abstractions. In one instance, a social worker tested whether the user could make informed decisions on a screen-based interface by co-assembling two prototypes, one tangible and one screen-based (see Figure 9), based on a selection of activities that the user enjoyed. The two prototypes helped the social worker further explore to what degree the user understood abstractions on the screen-based interface. This offered the social worker an even more in-depth understanding of the user's ability to make an informed decision.

Figure 9. Exploring how users understand abstraction with different interfaces

In another session, a social worker explored how the user would perceive and understand different examples of iconography and pictures by using the toolkit to create non-verbal means of communication based on their previous knowledge of the user's capabilities and familiarity with symbols (see Figure 10). By engaging in such activities, the social workers matured their understanding of the user's ability to comprehend different representations.

Figure 10. Symbols used to explore the user's ability to comprehend representations

Learning about such opportunities in the user's ability to participate offered great help in knowing how and when to involve the user in future proxy activities. The presence of users continuously confronted the social workers about their understanding of the user's capabilities, which sometimes turned out to be incorrect, or in need of adjustment. By participating in co-design activities, the social workers gradually matured their ability to give the people with ID a voice in a PD process. More comprehensive descriptions of how these situations of mutual learning unfolded can be found in [34].

C. Phase 2 – Findings

We summarize our findings around the two themes identified in the data during the analysis: *social workers' facilitation* and s*ocial workers' exploration*. The two themes highlight the observed case-specific discoveries relating to the overarching research question. The two themes are examples of how social workers acted as proxies in both facilitating the inclusion of people with ID into the design-making stages, and in turn, how this influenced the decision-making processes and explorations of possibilities that these generative techniques allowed.

1) Social workers' facilitation

This theme outlines our understanding of how the social workers utilized their knowledge about their users' capabilities to include them in the workshop using the tools that different techniques offered to facilitate for engaging user participation.

Initially, we intended the activities to engage the users passively in similar, albeit arbitrary, activities such as board games, artistic activities, or any activity that resembled the generative sessions. The results, however, uncovered that the social workers utilized their understanding of the users, their communicational capabilities, and understanding of practice and meaning, to include the users into the generative design sessions. This effectively made the users more directly involved in the design activities than initially intended.

2) Social workers' exploration

Throughout all stages of Phase 2, the social workers actively engaged the users in mutual learning. They explored their assumptions about users' capabilities and concrete ideas utilizing both existing and new tools to engage the users. The inclusion of the users also opened up possibilities for the social workers to explore through discussion with peers and researchers by sharing ideas and furthering their understanding of capabilities and technology. Finally, they also matured their understanding of how they could involve people with ID into generative design activities when serving as proxies. Table VI summarizes the two themes and related main findings.

TABLE VI. THE TWO THEMES AND RELATED MAIN FINDINGS

Themes	Main findings
Social workers facilitation	• Social workers can facilitate for engagement of user participation • Tools and techniques enable social workers to engage user participation
Social workers' exploration	• User participation let social workers inform themselves and the researchers about the users' capabilities • Social workers utilized and created tools to facilitate exploration • The social workers' exploration opened possibilities for discussing with peers and researchers

VII. Using Social Workers as Proxies to Facilitate Participation

In the immersive nature of our PD process, taking on the role of a volunteer social worker gave us a possibility to create and embed mutual learning in the context on the premise of the users and social workers. In Phase 2, the basis for further exploring possibilities for participation of people with ID was built on an understanding of the context through the four themes presented as our intermediate learning outcomes. We operationalized these themes as six guidelines that helped us inform the use of tools and techniques as a means to enable participation from the user through the inclusion of social workers as proxies. Having engaged with users and their proxies in generative workshops now allow us to structure a discussion around our overarching research question: "h*ow can we facilitate design with people with different intellectual capabilities using Participatory Design?".* We have divided the discussion into two main arguments that reflect the core idea of the strategy we advocate for facilitating PD involving users with ID.

A. Enabling appropriate proxies can facilitate the inclusion of people with ID into all design stages

The use of proxies has been discussed in previous studies, e.g., as a way to help researchers learn about the goals of the end-users [24]. However, we argue that the social workers specifically constitute appropriate proxies due to their ability to break down language barriers (as seen in [23]) that may prevent equalized power relations. Both throughout the immersive process of Phase 1 and the generative sessions in Phase 2, the proxies were vital in bridging communicational gaps. This point is best exemplified by cases where the users relied on mixed forms of communication, e.g., hand signs, body language, and words, to express themselves. In such situations, both contextual knowledge and having the social workers explicitly tell you what they think the users were communicating, enabled participation from the users.

While conducting the different generative sessions in Phase 2, the social workers actively engaged the users in all stages, utilizing their knowledge about physical, communicational, and general cognitive capabilities to activate and engage them in design-making using both existing and new tools [35].

Balancing power relations is a common challenge found within PD [3, 5]. During both phases, the social workers' presence during activities increased the researchers' chances to successfully facilitate a space for mutual learning by supporting non-verbal and contextual forms of communication. Users were able to express themselves, make choices, and be properly understood. Being able to speak your native (to the context) language in the design process can avoid issues of "model monopoly" and expand the universe of discourse [2]. Facilitating sessions in a larger arena that allowed the users to practice collaborative working skills was seen as highly dependent on the presence of the social workers in our study, and other studies have suggested that this factor is often overlooked [25]. We also want to shed light on considerations related to the management of the design process [5] and advocate the use of social workers to help lower the threshold for participation as they know how to initiate design discussions without disrupting ongoing everyday activities. One such instance was during Phase 1 where the social workers approached us to discuss topics of interest. Another more prominent occurrence was in Phase 2, where the social workers actively engaged in planning when, where, and how we would conduct the different sessions, considering daily routines and needs of the users.

To engage the participants differently, we used contextual probes [22, 36], both as a way to circumvent users finding themselves in a "passive role" [30] due to communication barriers, and as means of sensitizing the proxies, forcing reflections on their roles as design-proxies and facilitators for user-participation [10].

B. The inclusion of people with ID by proxies lets proxies explore assumptions about user capabilities

The people with ID participating in the generative sessions could inform the proxies about their different capabilities *during* the decision-making stages of design. In the field PD, it is mutually agreed that the heart of the tradition is participation [9, 37]. Brandt et al. [9, p. 147] point to Wenger [38, p. 56] and their definition of participation in a community of practice as a "complex process that combines doing, talking, thinking, feeling and belonging. It involves our whole person including bodies, minds, emotions, and social relations". In our study, the bodily presence of people with ID helped enrich the design sessions, effectively giving the end-users another means of communicating needs [21].

While proxies constitute a vital part of bridging potential communication gaps and leveling power relations, we argue that generative tools and techniques, such as those described by [10], can open up the design space for the users by permitting different means of expressing wants and needs by utilizing channels of *telling, making and enacting* [9].

In Phase 2, we observed that despite substantial limitations due to physical and cognitive capabilities, people with ID contributed to decision-making, through the presence of either mind or body. This expands on earlier studies that focus on the inclusion of people with ID, and other cognitive limitations, into initial inquiries and later testing stages [6, 7, 19, 20]. In their respective studies, [6, 7], made it possible for users to "show, share and interact" in later testing stages by utilizing prototypes. Here, we enabled the proxies to "show, share and interact" during earlier stages, which granted the proxies a greater understanding of capabilities when ideating. We postulate that the inclusion of people with ID into the design-making makes it possible to fail fast and find solutions that better resonate with the end-users earlier in the design process.

Through different generative sessions in Phase 2, proxies utilized the tools available, both existing and new, to generate or verify knowledge about the users' capabilities. In their work, Brandt et al. emphasize enacting as an important component in any PD process, where we utilize the physicality and accessibility of the end-users to explore possibilities for future use: "With enacting we refer to activities where one or more people imagine and act out possible futures by trying things out (by use of the body) in settings that either resemble or are where future activities are likely to take place" [9, p. 164]. In the case of people with ID, who might be unable to express wants, needs, likes, or dislikes through traditional communicational means, we argue that the embodied means of communication becomes particularly important in exploring future use. In our study, the physical presence of the people with ID, and the possibility for proxies to enact scenarios of use by utilizing their knowledge about users' physical and communicational capabilities let them explore future possibilities of use.

VIII. Enabling People With ID to Participate

We consider the main contribution of this paper to be our proposed immersive strategy on how to include people with ID in PD processes by engaging social workers as facilitators. We have put forward and discussed the two overarching arguments of our approach: that the process can (1) enable appropriate proxies as the facilitators of the inclusion of people with ID in all design stages, and (2) let proxies explore assumptions about users' capabilities as they facilitate the inclusion of people with ID. Our findings demonstrate different ways the presence of social workers enabled dialogue in ways that supported non-traditional forms of communication, strengthened core principles of PD such as mutual learning, and allowed people with ID to engage in decision-making. As such, we consider our findings to contribute to ongoing discussions on a method level of how to engage people with ID in specific PD activities, as well as relevant to methodological discussions where we suggest using immersion as a strategy to facilitate long-term PD collaborations. We end the paper by positioning our propose strategy into two central discussions with the PD community, namely how our strategy builds on top of established forms of mutual learning and practice, and that it should be organized as a long-term commitment.

A. The PD process should be built on top of already established forms of mutual learning and practice

One core concept of PD is to enable participants to take control of their futures by affecting the technology that will help shape it [2]. Technology intended to support vulnerable users carries a responsibility of not affecting the users' everyday lives in a negative manner, for instance, through use or even the inability to use. One such example is stigmatization through technology, which has previously been reported within our empirical context. Havgar [39] discusses the importance of not disrupting the sense of feeling "normal" for people with ID through technology that separates them from the rest of the world. Similar challenges have been reported in other demographics as well, e.g., PD involving older adults [40]. We argue that one of the essential reasons we have been able to include people with ID into decision-making processes has been based on utilizing established forms of mutual learning and practice.

However, in order to get to a 'starting line' [7] where inclusion into ideation is possible, we argue that immersion offers a chance to learn about everyday activities where people with ID and their social workers already have established mutual learning through their everyday activities. We have demonstrated how building on top of established means of communication may contribute to the participants accessing a sensation of mutual learning quicker [24], as well as taking more ownership of the design process and its outcomes [41]. Scaffolding the PD process around existing routines and habits allows for easier participation for social workers who find themselves in a busy work environment. This may also reduce misunderstanding as social workers are more familiar with the individual users and can assist the researchers in their interpretation of non-verbal forms of communication [42]. Lastly, we argue that building on top of already established practice, routines, and mutual learning has let us shape a PD process that omits problems such as described by Redhead & Brereton [3], that academic practice can be resisted by the local community.

B. The PD process should be organized as a long-term commitment

Identifying the appropriate point of departure in a PD process demands contextualized knowledge [7]. However, we argue that contextual insight over time contributes to mutual learning by allowing time and space to identify enough examples of the uniqueness of each situation being symbiotically shaped by the users, the context, and the social workers' intimate knowledge of the situations. As such, we argue that long-term engagement is a way to converge on the uniqueness of each situation [6], as well as a way to avoid communities rejecting opportunities for collaboration due to short-burst facilitation [3].

Furthermore, we saw from our empirical context that committing to long-term engagement also contributed to both respect and trust [7], and the development of social relationships and skills [24]. This gave the activity center more time to familiarize themselves with our academic practice.

Finally, we also advocate long-term presence as a means to support "channeling" the access to the context and the co-inhabitants' needs [8], which we argue is not a static matter, but rather something *"[...] continually in the making through everyday contestations among neighbors, relatives, colleagues and the material world they co-inhabit."* [43, p. 15]. In these situations, the active engagement of social workers as proxies contributed significantly to adapting the process to both user needs and daily routines and practices. The long-term presence also meant that the social workers and researchers developed an understanding of how to work around issues such as the need for flexibility due to specific needs or physical and mental fatigue, a point also raised by [6, 19].

IX. Conclusion

This paper has reported from the exploration and facilitation phase of a long-term PD process involving people with ID and social workers as proxies. We have proposed using immersion as a strategy to elicit contextual concerns that can later shape tools and techniques applied in PD activities. Concrete experiences were used to demonstrate how we built a PD process on top of daily activities and routines of the people with ID at the activity center. The results from our empirical work highlight examples of how we have managed to enable long-term participation by finding new ways to achieve mutual learning and decision-making. Our proposed strategy emphasizes the vital role of the social workers as the enablers of participation from people with ID.

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