International Journal on Advances in Intelligent Systems

2024 vol. 17 nr. 3&4

The *International Journal on Advances in Intelligent Systems* is Published by IARIA.
ISSN: 1942-2679
journals site: http://www.iariajournals.org
contact: petre@iaria.org

International Journal on Advances in Intelligent Systems
Volume 17, Number 3 & 4, 2024

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Addressing Digital Exclusion via the Inter-Generational Codesign of Extended Reality, Underwater Telepresence, Social Games, and Voice AI Technologies

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***Abstract*— Older people throughout the world tend to be digitally excluded. Regional deprivation multiplies this effect with younger people in deprived regions also digitally excluded. Codesigning digital technologies, using the natural and heritage resources of such regions would address this, but is rarely done. We present our methods and preliminary results, two-thirds of the way through a 30-month project to develop novel technologies in extended reality, underwater telepresence, digital social games, and artificial intelligence voice interfaces and to use these assets to tackle digital exclusion. We are taking an intergenerational approach, working with 36 partner organizations, some to identify possible technologies and others to help with recruitment. Between August 2023 and June 2024, we ran thirty inter-generational codesign workshops for extended reality (11), underwater telepresence (10), social games (6), and voice interaction (3) with a total of 95 attendees (53 older (50+ years old) and 42 younger (16-30 years old) participants). In total we aim to recruit 120 participants (80 older, 40 younger) and codesign four new technologies. We present our experiences in recruitment and workshops. This has lessons for (i) other regions facing similar issues of digital accessibility, (ii) those codesigning novel technologies for older people, (iii) those working in extended reality, underwater telepresence, digital social games, and voice interfaces.**

Keywords- digital inclusion; codesign; coastal regions: extended reality; underwater telepresence; digital social games; artificial intelligence voice interfaces.

I. Introduction

We have presented a preliminary (halfway) report on our project entitled "Intergenerational co-creation of novel technologies to reconnect digitally excluded people with community and cultural landscapes in coastal economies (ICONIC)", funded by the UK Research and Innovation Engineering and Physical Sciences Research Council [1]. Here we expand on that report giving an update, unpublished information related to the original content, new details from a further six months' work, in particular including progress from further workshops.

Older and younger people living in coastal and rural areas, such as Devon and Cornwall (D&C) in England, face significant health inequalities [2] [3]. In other countries such as Spain it may be rural areas in the country interior that are more deprived. Although most solutions often lie with politics and economics, the codesign of human-centered digital technologies that reduce inequalities and empowers an equitable digital society, is also imperative. Three types of digital equity exist: (i) digital connection – being able to access the same digital facilities and services as everyone else; (ii) digital employability – having an equal chance for jobs in the digital economy and (iii) digital enablement – using digital to have equal chance of participating in aspects of society otherwise denied.

The benefits of a digital society are not equally distributed across different demographic and socioeconomic backgrounds. For example, older people often do not use digital technologies at all, or only minimally due to inequity in digital connectivity and enablement [4]. Furthermore, while older people's links with community, resources and meaningful activities are essential in supporting health and well-being, these links are increasingly dependent on a digital connection, often meaning Digitally Excluded Older People (DEOP) are at risk of being engulfed by an additional sphere of exclusion. For Younger People (YP), digital employability equity is of greater concern with disparities in opportunities for digital employment and career aspirations.

In England, the most disadvantaged regions are often coastal, characterized by areas of low productivity and high deprivation. Traditional industries, such as farming, mining, fishing, and port activity, have all declined, with alternative, often high-wage digital sectors struggling to emerge, resulting in an exodus of younger skilled people. Those left behind, may be from poorer backgrounds, lacking secure and well-paid jobs, or a clear sense of career ambition. Disadvantaged regions need to use the assets they have to try to address such digital inequalities. In England, many coastal regions, including D&C, have social, environmental and heritage assets. While access to such cultural and environmental assets are known to improve health and wellbeing, equitable access is not always available to older people. And the converse is also true, that digital equity is important for the economy of 'left behind' coastal regions. Digital technologies are becoming essential in presenting and connecting with local culture. The cultural landscape together with community groups makes a cultural ecosystem that gives a region its unique identity, helping to promote its economy to the outside world [5].

Technology for intergenerational connectivity is an emerging field [6]. Lack of technical support is often the main contributor to digital exclusion among older people. YP often adopt new technology quickly so can act as 'digital champions' for DEOP. Positive benefits of intergenerational activities are also widely reported for YP, many related to educational and developmental gains and improved attitudes towards older people [7]. Work with companion robots demonstrated well how YP's design ideas for technology may be different from older people's expectations [8]. However, intergenerational codesign may bring ideas that older people had not thought of but are acceptable and useful.

Research codesign is now widely used [9] [10] and there is prior research on intergenerational digital codesign [11]. Our project learned considerably from the prior work on the Generating Older Active Lives Digitally (GOALD) project funded by the Economic and Science Research Council [12]. GOALD tried to take an intergenerational approach to digital design but had problems in recruiting younger people [13]. Nevertheless, we learned from their experience in running codesign workshops and from the guidance for developers of digital products for older people that they produced [14].

The ICONIC project is a 30-month project. We are taking an intergenerational approach to address digital exclusion in older people and digital economic and employment exclusion of younger people. It is important to know if being intergenerational is a necessary component of codesign. We need to know if and how this approach leads to differently designed more inclusive technology. We have chosen four technologies that may connect people to community and cultural landscape in our coastal region: extended reality, underwater telepresence, digital social games, and Artificial Intelligence (AI) voice interfaces.

Immersive experiences can help improve wellbeing for people unable to visit certain places due to mobility problems. This is a major issue for heritage sites, sites of special scientific interest, and coastal landscapes where there is often limited ability to modify construction. Climate change, flood and coastal erosion create additional risks and put increasing pressure on the need to facilitate novel and sustainable visitor experiences, and tourism [15]. *Extended reality* (XR) allows people to experience those spaces virtually and enjoy the wellbeing and psychological benefits. A better understanding of the importance of the marine environment enables us to take this a step further into *underwater telepresence*, celebrating the rich marine environment of D&C.

Connecting with others helps address social isolation and in that respect the importance of technologies, such as videocalls, has been demonstrated in care homes and for people unable to travel during the pandemic. But often more is required than just the opportunity to talk. *Digital social games* have been shown to be a key motivator in connecting, educating, and engaging people and more importantly keeping people engaged as well as reducing stress from prolonged isolation [16]. They offer possibilities for the communication of specific values and information while simultaneously engaging previously disconnected audiences. Digital games also have the capacity to engage hard to reach audiences and minority groups but also allow for the valorization of heritage, often a strong motivation for rural regions and marginalized groups. While more generic history-themed digital games are commercially available, the potential health and wellbeing benefits of digital games based on the specific history and historic environment related to the cultural identity of D&C had not yet been explored and so is a focus of ICONIC.

Finally, while the three technologies above can be used to engage individuals with some level of digital awareness, skills and device ownership, we need ways to engage those most digitally excluded - those without internet access or digital devices. This group, for reasons of cost, awareness, lack of skills and/or support perhaps due to isolation may never use broadband or own a digital device but nevertheless can be connected to the digital world through existing phone technology. *Voice interaction with the internet* is now commonplace through smart speakers but making that available by telephone to an older internet naïve population has had little research. Voice interaction by phone via chatbots to community and cultural resources could help re-connect DEOPs, particularly those with visual impairments.

The ICONIC project therefore aims to codesign appropriate and human-centered technologies focusing on extended reality, underwater telepresence, social games, and voice AI. The project is trying to capitalize on existing cultural and environmental assets in D&C to address challenges faced by both DEOP and YP. ICONIC is necessarily an inter-disciplinary project with a team drawing on computing science (including AI, games, robotics, vision), public health, psychology, architecture, art and design, history and heritage, marine biology, and business studies.

The rest of this paper is structured as follows. In Section II we present ICONIC's research questions and in Section III, the objectives. As this paper focuses on methods, in Section IV, we present our methods in detail. Preliminary results and discussion are in Section V. Section VI concludes our article.

II. RESEARCH QUESTIONS

The six main research questions for this 30-month project are: (i) Is intergenerational codesign of the four identified technologies feasible? (ii) Does intergenerational codesign promote an equitable digital society in coastal Britain? (iii) Which of the four technologies are more susceptible to intergenerational codesign and what preferences do DEOP and YP have in using these technologies? (iv) Which approaches lead to a sense of connection with community and cultural landscape for DEOP and help develop confidence, communication skills, and employability for YP? (v) Does intergenerational codesign lead to differently designed technology with more potential for inclusivity? (vi) What are the technical and social requirements to develop, adopt, scale-up, spread and sustain these technologies?

III. OBJECTIVES

The objectives of ICONIC include: (i) To engage with local partners who will help with recruitment and who have various digital resources related to the social, environmental, and heritage assets of the region; (ii) To recruit 120 participants (80 DEOP, 40 YP) with the help of those external partners; (iii) To codesign four novel technologies by taking an intergenerational approach in a series of workshops; (iv) To document group working by external observation and internal reflection to assess the impact of intergenerational working between the four technologies on design; (v) To assess whether using the four codesigned technologies improves digital access and wellbeing and sense of connection for DEOP or digital involvement or digital employability of YP; (vi) To explore sustainability through opportunities of embedding these processes into curricula for further and higher education students and in the creation of a social enterprise partnering university and community groups.

IV. METHODS

A. Regional Partner Organisations

An initial stage (Objective (i)) was to recruit and meet with partners to explain ICONIC's aims and to explore their related resources and needs. By June 2024 we had met with and had the support of 36 organizations (Table 1). Some partners had both resources and experience of using digital to engage with the digitally excluded. For example, the Ocean Conservation Trust runs the 'Oceans For All' sessions, in which care home residents can view 360 degree videos recorded inside the tanks of the National Marine Aquarium (NMA) in Plymouth, and Geevor Tin Mine in Cornwall have developed a Virtual Reality (VR) tour to provide remote access to their 18th Century mine-workings heritage site. Other partners provided 'the challenge' such as remote villages Pendeen and Carnon Downs in Cornwall. In some cases, partners provide technology that needs further development. For example, to support voice AI development, we are working with a small and medium enterprise (SME) PatientCards that has a social prescribing network that can be accessed through the Help@Hand mobile application. With Pendeen village we are working with community members who provide 'Outreach Pendeen' a community newsletter containing details of local services, activities, and community groups (see Section G).

B. Recruitment of Participants

We have worked with our partners to recruit older people (aged 50 or over) and younger people (aged 16-30) (Objective (ii)). The project has ethical permission from the University of Plymouth Arts, Humanities and Business Research Ethics and Integrity Committee (09/05/23; project ID 3941). Our primary method of recruitment has involved recruitment partners (Table 1) sharing adverts of the project with potential participants. This strategy was supplemented through contacting additional groups (such as the University of the Third Age, a network that supports education for retirees) that are not partnered with the project directly, to attempt to recruit participants that are 'digitally excluded'. Partner recruitment success has been varied, with some partners unable to source interest in the project and others providing many participants. For example, prospective rural community partners reported no participation interest amongst individuals in the older, rural communities that they work with. Other partners embedded in rural communities were much more successful and contributed sufficient participants to embed a codesign workshop group with them. Further recruitment of YP was conducted through our University, to ensure an intergenerational component for the workshops. Although university students are not a good fit for 'digitally excluded', some, such as nursing students, may not be particularly digitally proficient, and given problems of recruiting younger people, we have compromised to ensure the intergenerational aspect of the project. Participants are reimbursed for their participation with vouchers, with additional vouchers available to cover costs of transport and time to travel to the workshop venue. Before their first workshop, we meet with participants either in-person or remotely (via phone or Zoom) and they are interviewed to gauge their current engagement with digital technologies, local heritage and the environment, and their local communities. By the end of June 2024, we had recruited 53 DEOP and 42 YP. Outside of networks within the University of Plymouth, recruiting YP has proven more difficult than recruiting DEOP due to workshops conflicting with working or education hours. This has been addressed through embedding asynchronous codesign workshops within work being conducted by community partners and further education (FE) providers in Cornwall that work with YP.

As participants are being recruited from diverse backgrounds, there is considerable variation in the nature of digital exclusion they report in recruitment interviews. Participants have reported barriers to accessing technologies, including lack of skills, costs, and poor local infrastructure [17]. One commonality across most participants, however, is a keen interest to learn more about the technologies being codesigned as a part of the ICONIC project. Participants have shown the greatest interest in the Underwater Telepresence technology, with XR a 'close second', as both technologies can be used to make difficult to access spaces more accessible to a wider audience. Social digital games has registered the least interest from participants, with some older participants reporting negative attitudes. The feedback, based on anecdotal evidence, seems to suggest that this negative attitude stems from the general portrayal of digital games in the media and a missing personal experience with games technology and digital games [18], linking digital games to violence and wasting time. Nevertheless, a core of 8 DEOP joined codesign workshops for the Social Games technology, taking ownership of the direction of the game design and the interpretation of the seagrass conservation theme (see below). This group can also later provide a more reflective picture of the specific games technology and games they engaged with, creating a more nuanced perception in the community which could lead to a shift of the community attitude.

C. Overview of the codesign workshops

Objective (iii) is to codesign four novel technologies by taking an intergenerational approach in a series of workshops. The iterative process of technology development we are using is like Participatory Inquiry approaches generating knowledge collaboratively and iteratively where research and action are linked through critical reflection [19]. Our approach is based on an extension of the Participatory Inquiry method called Research through Design [20]. Stakeholders are involved at all development stages of the project from initial problem-

TABLE 1. SUMMARY OF 36 PARTNER ORGANISATIONS SUPPORTING WORK ON THE ICONIC PROJECT SHOWING THEIR ROLE IN EITHER PARTICIPANT RECRUITMENT (PR) OR TECHNOLOGY CONTENT (TC).

Partner	Brief Description of Partner	Role
Abbeyfield	Charity providing housing, residential care and support to older people [21]	PR
Age UK Cornwall	Charity supporting older people (federated independent branches) [22]	PR
Age UK Plymouth	Charity supporting older people (federated independent branches) [23]	PR
Carnon Downs	Village community/hall in Carnon Downs, Cornwall [24]	PR
Centre of Pendeen	Village community/hall in Pendeen, Cornwall [25]	PR
City College Plymouth	Plymouth Further Education college, providing education for students aged 16+ [26]	PR
CN4C	Social enterprise supporting individuals in Cornwall with economic/social issues [27]	PR
Cornish Mines	World Heritage Site preserving 18th and 19th century mining sites in 10 locations [28]	TC
Cornish Mining NT	Heritage Site preserving Tin Coast mining region: 3 locations in west Cornwall [29]	TC
Cornwall AONB	National Park (Area of Outstanding Natural Beauty) covering approximately 27% of Cornwall and comprising twelve separate areas, eleven of which are coastal [30]	TC
Cornwall College	Cornwall Further Education college, providing education for students aged 16+ [31]	PR
Cornwall Digital Exclusion Network	Team embedded in Cornwall Council to support access to digital tools and services in Cornwall and the Isles of Scilly [32]	PR
Cornwall Museums Partnership	Charity that works collaboratively across museums in Cornwall to promote wider engagement with Cornish heritage [33]	TC
Cotehele National Trust	An estate with a medieval house that has been developed across the Tudor and Victorian eras additions located in the east of Cornwall run by National Trust [34]	TC
Dartmoor Nat. Park	Historic national park in south Devon with extensive Bronze Age heritage [35]	TC
Exmoor National Park	National Park located in Somerset and north Devon [36]	TC
Geevor Tin Mine	Historic 18th century mine site in west Cornwall [37]	TC
Healthwatch Torbay	Non-profit organisation supporting health and social care in Torbay, Devon [38]	PR
PatientCards	SME running the Help@Hand social prescribing mobile application used as information sources by the ICONIC Voice AI technology [39]	TC
Hi9	SME specialised in voice AI interfaces [40]	TC
iSight Cornwall	Charity supporting individuals with sight impairments in Cornwall [41]	PR
Made Open	SME that runs Cornwall Link and Devon Connect directory websites used as information sources by the ICONIC Voice AI technology [42]	TC
Minack Theatre	Historic open-air theatre in west Cornwall, with views over Porthcurno Bay [43]	TC
Mount Edgcumbe	Historic Park and stately home in south-east Cornwall [44]	TC
Newquay Orchard	Community group in Newquay, Cornwall [45]	PR
Nudge	Community group in Plymouth [46]	PR
Ocean Conservation Trust	Charity focused on ocean conservation, that runs the National Marine Aquarium, Plymouth [47]	TC
Plymouth CH	Plymouth Community Homes (PCH) - Large housing association [48]	PR
Plymouth Digital Exclusion Network	Team embedded in Plymouth City Council to support access to digital tools and services in Plymouth [49]	PR
Plymouth Sound National Marine Park	The UK's first national marine park, based in Plymouth Sound [50]	TC
Saltram National Trust	Park and Georgian stately home near Plymouth run by National Trust [51]	TC
South Devon AONB	'Area of Outstanding National Beauty' National Park located in south Devon [52]	TC
South Devon College	Further Education college in Torbay, providing education for students aged 16+ [53]	PR
St Austell Healthcare	GP practice serving St Austell and surrounding areas, working with PatientCards [54]	PR
The Eden Project	Attraction in Cornwall comprising domes housing emulations of natural biomes [55]	TC
Torbay Community Development Trust	Charity supporting community development in Torbay, South Devon [56]	PR

framing to the later development stages (for example, designing interactions). To accommodate the iterative nature of the codesign process, we have set up monthly time-boxed development windows and each technology will have between 7 to 10 workshops. From the technical point, this setup provides a suitable timeframe to plan, develop the technology, deliver the workshop, and analyze the results of the workshop to generate knowledge (Figure 1). One of the main benefits of the monthly workshops is repeated, consistent interaction with the participants: a key ingredient for building a productive collaborative relationship.

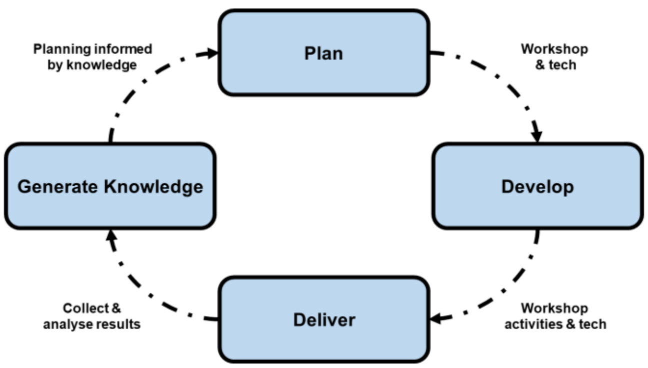

Figure 1. Monthly iterative process used to extract knowledge from the codesign process. The outcome of each process is being used to inform the planning and delivery of the next workshop.

D. Extended Reality (XR)

Our work with XR technologies aims to give older people with mobility impairments access to experiences in sites of cultural and historical significance, addressing the limitations of commercially available VR systems while creating bonds with specific places and communities. For example, older adults may have needs related to physical impairments such as visual (use of glasses with the VR headset) and aural (VR headsets interference with hearing aid devices) [57]. Current VR systems have a strong emphasis on the gaming aspect of the VR market, highlighted by the design of the individual controllers, which at the core is a gaming controller split in two. This can present challenges to the users with limited dexterity in their thumbs and fingers. In addition to technology adaption, content tailored to the older adults' interest is crucial to providing an experience that leads to acceptability and adoption [57].

This builds upon previous work on the development of XR systems for digital heritage, which focused on Powderham Castle and the Higher Uppacott medieval site in Dartmoor National Park [60]. We are focusing on Cotehele (Table 1), a site managed by the National Trust which preserves a series of medieval buildings and historic garden in Cornwall. Despite the best efforts of its local team to improve accessibility and the visitor experience, the site includes buildings with accessibility issues, such as narrow corridors and steep steps, and limited public transport.

Between August and December 2023, we ran five XR workshops. An introductory codesign workshop was held asynchronously with one rural workshop group in March 2024 and three further workshops were held with a group of students at a partner FE provider in June 2024, making ten workshops in total (Table 2). We used a Meta Quest 2 headset to give participants a VR immersive experience (Figure 2). Activities included multiple methods of documenting, experiencing, and speculating about historical sites and their potential to elicit wellbeing principles such as social cohesion and intergenerational interactions. These included 360 video demonstrations, persona-based experience design workshops, and activities to test ergonomics of XR hardware for older users.

Figure 2. Participant trying out a virtual reality environment via a head mounted display in one of the codesign workshops.

E. Underwater Telepresence

We want to give people the feeling of being underwater while onshore and to see an environment they have never seen before. Our initial codesign workshops revealed several barriers to engaging with the underwater world, such as financial constraints, time commitments, physical fitness requirements, and discomfort due to cold water. While initially, we intended to deliver the experience via a remotely operated vehicle, through a scoping review [60] we identified other potential technological implementations of underwater telepresence characterized by the trade-offs between accessibility, interactivity, as well as the complexity of installation and maintenance. Between September 2023 and February 2024, in partnership with the NMA, we ran five workshops. Activities included problem-framing, physical prototyping and educational technology demo sessions. As with the XR track, we also ran an introductory codesign workshop asynchronously with a rural workshop group in April 2024 and a further three extended codesign workshops were held with a group of students at a partner FE provider in June 2024, making nine workshops in total (Table 2). The Underwater Telepresence introductory workshop took place at the NMA and focused on identifying problem statements and identifying participant preferences for the technology following immersive demos. The extended codesign workshops for the YP mirrored the activities first completed by the original intergenerational codesign group, but also included digital prototyping of UI elements for stimulating and relaxing underwater experiences.

F. Digital Social Games

Games may be a key technology for engaging with younger user groups that are often otherwise hard to reach as they offer interactive engaging experiences. As people get older, the technology they use will often stay with them, affecting future generations of older people, playing games using digital technology. Traditional games and play [61], including chess, board games or storytelling, have a rich history and background in learning and shared exploration of knowledge with a strong social focus, which is often overlooked in the current debate on games. Social games add a stronger social emphasis and a social component into the mix, which allows the formation or retention of communities. How can we help them keep both older and younger people engaged and contributing? One approach we envisioned is the development of a new digital social game creation framework inspired by casual game creation apps [62] such as Wevva [63] that will provide co-creation groups with the technology for understanding, exploring, and creating games while not having access to more expensive computing hard and software. As games can be quite divisive, codesign is a crucial aspect of designing the framework along with the community to cater to the needs of the entire intergenerational group.

In discussion with project partners NMA "Blue Meadow team" we decided to focus development on the topic of seagrass and its growing process. The beneficial role of seagrass as part of the local ecosystem and its ability to combat the effects of climate change identifies with the ethos and beliefs of the local coastal community. The topic also provides links to another ICONIC technology namely underwater telepresence and builds on local strengths. The codesign process for social games started in February 2024 and has been working with two groups (i) the main workshop group completing five workshops and (ii) an asynchronous group embedded within a partner completing two workshops, making seven workshops in total (Table 2). As all workshops they followed the iterative approach to knowledge generation (Figure 1) enabling the capture and integration of the codesign team's feedback and suggestions into the game development process. Game development, in general, is mainly concerned with the "construction" of the game and it is focused on bringing together elements such as game design, programming, art creation, sound design, level design and more [64] [65]. Game development for our Social Game, follows a similar approach, with most work being carried out by the development team with input from the codesign participants. The codesign team's primary role is conceiving and creating the way the game works, with a particular focus on player experience, core actions and theme.

Figure 3. Participant sharing ideas in a social games codesign workshop.

Figure 4. Working with National Marine Aquarium "Blue Meadow team" we are focussing games development on seagrass and its growing process.

G. Voice AI (Phone-based Access to Internet Services)

Nearly 40% of those 75+ in the UK had never used the internet in 2020 [66]. Providing them with phone access to the Internet is one way to address such digital inequality. But even among those with internet access, previous research has shown that older people may abandon voice assistant services on smart speakers after unsuccessful attempts [67]. We are working with older and younger participants to discover how older people with no previous computer experience want to interact with various resources. The main objective is to create bidirectional voice communication with internet services through phone calls, which can be achieved through an IP phone (IP PBX) server that is called by the DEOPs so that it connects them to the application programming interfaces (APIs) of the cloud-based voice assistants (e.g., Amazon Alexa) and services (Caller Smart Speaker API). These intelligent assistants receive voice-based instructions or questions from DEOPs and reply to them through the phone using the available information online or through the other connected service APIs.

We have explored three contexts: (i) existing audio content from Cornwall Museums that had previously been made available via smart speaker [68] (ii) and 'social prescribing' [69]. For the initial development stage, we focussed on the local events and services, exploring the social prescribing aspect of the technology, with the view of further including other sources of information. Social prescribing is an approach to connect people to community activities, groups, and services for their health and wellbeing in primary care. For this first stage we are supported by our content-provider partners: Patientcards Help@Hand mobile application for community group information, Cornwall Link [70], a web platform managed by Made Open for AgeUK Cornwall, and local Pendeen village newsletter Outreach. As our application is location dependent, our initial development has focused on (i) Help@Hand application, running codesign workshops in St Austell area, and (ii) working with Pendeen village and their community newsletter (Figure 5).

We have been conducting codesign workshops with two groups in Cornwall starting in January 2024. Our rural community group has taken part in three codesign workshops focusing on Voice AI technology, and another group based in St Austell is taking part in workshops focusing on access to social prescribing resources in the local area, using the Help@Hand database and has so far had one workshop making four in total (Table 2). These workshops will be employing common conversational interaction design tools like Wizard-Of-Oz (WoZ) for prototyping [71]. Our pilot workshop revealed a need to explore subtle voice interaction features like pauses and intonations for natural voice interaction. We have partnered with the University of Exeter's conversational analysis group to study these features to enhance user satisfaction and engagement in the provided service. Early codesign workshops with both groups have focused on the problem statement for this technology, highlighting difficulties in coastal and rural digital infrastructure. Additional activities have included demonstrations of related technologies (e.g. smart speakers, large language models) and early-stage evaluation of phone-based Voice AI prototypes. Later workshops included prototype testing based on Anthropic Claude-3 Haiku LLM model and supported by real-time speech recognition and text-to-speech engines.

Figure 5. Voice AI workshops have been with two communities. One of these is via a community newsletter "Outreach" for Pendeen village.

H. Exit Interview, Evaluation and Analysis

Participants will be interviewed on leaving the study to gauge their assessment of the intergenerational interactions within the workshops. We will also use workshop recordings to identify patterns in how the generations work together or if there are specific technical preferences associated with either age group. Some preliminary observations from workshops for the first two technologies suggest that DEOP tend to take the role of 'directors' and let the YP do the hands-on design activities/idea presentation. We will adapt and adjust our methods to try to get the best from this aspect of the study design. The participant 'exit interview' will be used to assess whether using the four co-created technologies improved their digital access, wellbeing and sense of community and environmental connection (for DEOP), or digital involvement and digital employability (for YP) (Objective (v)). Finally, we will be discussing with the further and higher education providers among our partners how to sustain opportunities and embed these processes into curricula for their students (Objective (vi)).

V. PRELIMINARY RESULTS AND DISCUSSION

We are making progress in our aim to develop four novel technologies codesigned by intergenerational groups of people who are in some way digitally excluded living in coastal communities.

A. Recruitment and intergenerational interaction

We managed to engage 36 partner organizations and by June 2024 had recruited 95 of our target 120 participants for workshops. Our approach in offering participants direct reimbursement appears to be more successful than methods used in GOALD [12][13]. However, recruitment has been difficult due to the requirement of older participants to be digitally excluded, and the availability of YP, means that we have not yet reached the same direct intergenerational participant balance within workshop groups as other projects [72]. Attracting DEOP has required a focused effort to work with the project's partners to share ICONIC's messaging. This has proven a successful approach, as it has allowed us to set up workshops in digitally marginalized areas. In these workshops participants have articulated clear issues with the local digital infrastructure. A further barrier has been a lack of interest in the project from some groups due to the desire for more foundational access to technology, that can offer practical support for using digital technologies. This has been particularly evident with some village partners supporting our recruitment efforts but being unable to successfully recruit participants in their local communities to the project. It is difficult to recruit YP for synchronous events as they may be working or studying during daytime when DEOP want to meet, but our work to date has shown the importance of intergenerational collaboration [73]. Asynchronous codesign workshops have allowed us to expand our reach for younger participants, supported by our external partners, following techniques employed in response to the COVID-19 pandemic

[74]. Whilst this does not provide direct intergenerational interaction, we have been able to introduce the different generational groups to the other generation's respective priorities for the XR, Underwater Telepresence, and Social Games technologies. This has revealed some similarities and differences in perspectives and outlook on problem statements, ideation, and interactive components of these technologies, driving the codesign process forward.

TABLE 2. SUMMARY OF CODESIGN WORKSHOPS

Technology	**Workshops**
Extended Reality	10
Underwater telepresence	9
Social Games	7
Voice AI	4
Total	30

A further lesson from the codesign sessions is the importance, when working with digitally excluded older adults, to articulate the researchers' impartiality, and emphasize the need to learn about the difficulties. Part of this messaging involves clearly explaining that the project is not designed to promote technology, but to identify how technology can support societal inclusion and support vulnerable populations, and also identify current barriers that prevent access to digital resources for vulnerable populations.

B. Technology developments

Our XR workshops have resulted in the development of bespoke controlling and handling functionalities for the Quest 2 headset. We 3D scanned and documented artefacts for the Cotehele team as part of our partnership working. As part of the workshop held at the FE college, students were introduced to photogrammetry as a methodology for capturing 3D objects digitally. Ongoing XR workshop activities focus on addressing the integration of locomotion and interaction design elements, and to incorporate narrative and storytelling strategies on the final codesign of XR experiences.

Underwater telepresence workshops have shown a preference for an immersive, real-time experience of a local underwater environment with on-demand access to information about the surroundings. These preferences have been distilled into a prototype of a live video streaming from a static 360 camera with a backend marine life classification engine and a simple user interface (UI) delivered over the head-mounted display with interactive controllers.

For digital social games we created 6 design values, that enabled the codesign team to focus on one aspect of game design in each workshop with the last workshop being reserved for testing and evaluation. The six design values (i)Theme, (ii) Player Experience, (iii) Challenges, (iv) Decision making, (v) Skills and strategy, and (vi) Look and Feel. Our overall aim, to be pursued in subsequent workshops, is to use the approach, lessons and tools developed during the codesign process as the foundation of an open-source framework that will enable the development of similar games through a social enterprise.

In the voice AI workshops participants expressed diverse attitudes towards the application with feedback surrounding the quality of the information provided and clarity of the voice. Some concerns regarding privacy and absence of emotion awareness of the system were also expressed. As the application is still being developed, we will iterate the prototype based on participants' feedback.

C. Limitations

Finding a niche for new technology development is difficult given the rapidity of background technology developments. This is an unusual project in that we work hard to engage the digitally excluded and with them to identify novel technologies while novel technologies are most frequently designed by those deeply embedded in and at the cutting edge of technology development. We are trying to be in 'two places at once' – looking at the digital accessibility needs of those who are infrequent users of technology, trying to make sure their voice is heard by technology developers.

Our project's impact may be limited by the short timescale of digital developments. We may also be limited by the findings from this one geographical locality. It may therefore be difficult to find generalizable design recommendations, but we hope that at least the observations on our methods will be generalizable to other locations.

VI. CONCLUSIONS

Recruiting older and younger people who are digitally disadvantaged to participate in the codesign of four novel technologies that make use of regional cultural and environmental resources is a difficult 'space' to occupy. However, we are making good progress in doing that and are producing novel technologies in extended reality, underwater telepresence, digital social games and AI voice interfaces. We think it is worth the effort and through design will help to address digital exclusion. Further work is needed to explore methods such as our asynchronous approaches to intergenerational codesign in other settings. Further work is also needed to assess the impact on digital inclusion of new technologies, for example, the use of voice interfaces in social prescribing, if embedded in routine services.

ACKNOWLEDGMENTS

This paper is presented on behalf of the ICONIC project that includes Katharine Willis, Daniel Maudlin, Chunxu Li, Sheena Asthana, Kerry Howell, Shangming Zhou, Emmanuel Ifeachor, and Hannah Bradwell as co-applicants and advisors and Lauren Tenn (Media and Administration Officer). We thank our 36 external partners (Table 1) and participants.

Intergenerational co-creation of novel technologies to reconnect digitally excluded people with community & cultural landscapes in coastal economies (ICONIC) is funded by UK Research and Innovation Engineering and Physical Sciences Research Council Grant Ref: EP/W024357/1.

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Applying a Technical Reference Architecture to Implement a Microservices-based Insurance Application

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***Abstract*—To overcome the shortcomings of traditional monolithic applications, the Microservices Architecture (MSA) style is playing an increasingly vital role in providing business services. This also applies to the insurance industry, which is facing challenges like cut-throat competition and decreasing customer loyalty. Providing scalable and resilient services of high availability in a flexible and agile manner, which comes with the MSA style, is undoubtedly a competitive advantage. However, the insurance industry's application landscape is characterized by the coexistence of historically grown systems based on different architectural paradigms. Therefore, the integration of microservices with Service-Oriented Architecture (SOA) services or even legacy systems induces additional complexity. A reference architecture may lower the complexity of this integration task by defining an architectural framework of MSA-based applications in a heterogeneous environment. In this contribution, we present a technical reference architecture for our partner insurance companies. The reference architecture is shaped along a cloud-native approach to provide good scalability, short release cycles, and high resilience. As a key feature, a technical microservice supports the integration of SOA services. To demonstrate the applicability of the technical reference architecture, it is used to implement a typical insurance business process in the context of car insurance. The target architecture comprises four business microservices and a SOA service managed by an ESB.**

Keywords*—*Microservices Architecture; Reference Architecture; Cloud Native; SOA; Insurance Industry.

I. Introduction

In this paper, which is an extension of a previous paper [1], we look at implementing the technical reference architecture in the insurance industry via a cloud-native approach.

A long-lasting trend in software engineering is to divide software into lightweight, independently deployable components. Each component can be implemented using different technologies because they communicate over standardized interfaces. This approach to structuring the system is known as the MSA style [2]. A study from 2019 (see [3]) shows that the MSA style is already established in many industries, such as e-commerce. However, this is rarely the case for the insurance services industry.

Our current research is the most recent work of a long-standing, ongoing applied research–industry cooperation on service-based systems. This includes cooperative work on traditional SOA, Business Rules and Business Process Management (BRM/BPM), SOA-Quality of Service (SOA-QoS), and microservices [4]–[7], between the *Competence Center Information Technology and Management (CC_ITM)* from the University of Applied Sciences and Arts Hanover and two regional, medium-sized German insurance companies. The ultimate goal of our current research is to develop a 'Microservice Reference Architecture for Insurance Companies' (RaMicsV) jointly with our partner companies. This shall allow the building of microservice conformant insurance application systems or at least such system parts.

However, several cornerstones and resulting challenges exist frequently in the German industry domain for this purpose. Insurance companies rarely start development 'in the green field' but must integrate and comply with existing application systems, like Knoche and Hasselbring showed in [8]. This requirement stems from building complex systems over multiple years, or decades even, where a significant bang replacement is too risky and cost-intensive. For example, our partners both operate a SOA and additional 3rd party software, such as SAP systems, which both have significantly different characteristics, for example, for testing, release cycles, versioning, administration etc.

Nowadays, our partners would like to get the promised benefits of microservices, such as improved scalability, both technical and organizational, through parallel execution and also parallel development, significantly faster release cycles, (a few weeks or even days instead of quarters or several months) etc. However, a microservices-based approach to help them must still work well in 'cooperative existence' with their existing systems and SOA services. Thus, improvements or partial replacements of their existing software landscape for particular goals using microservices is fine. Still, a complete migration to the Microservices Architecture style is not a feasible option. The main goal is to extend a system and not replace it.

In our previous work [9], we already developed RaMicsV, a logical reference architecture considering those insurance industry specifics. Moreover, we explored parts of it, such as logging, monitoring, security, workflows, and choreographies, in more depth (in [9]–[11]).

As the major contribution of this article, we present a technical reference architecture for RaMicsV. Our technical reference architecture (T-RaMicsV) is based on a cloud-native approach for microservices, including, for example, containerization, message-driven communication, and an ESB-wrapper microservice. In addition to the contents of our previous work [1], we also present the application of a typical insurance business process (Car Insurance Process), based on insurance business microservices within our technical reference architecture. In this implementation, we have selected and used a selection of technologies, such as Kubernetes for container orchestration, Apache Kafka for message-driven communication, and Keycloak for security-related topics. This is to be seen as one possible example of implementing our architectural considerations.

We organize the remainder of this article as follows: After discussing related work in Section II, we briefly repeat RaMicsV in Section III. Next, Section IV and Section V contribute our cloud-native approach to the technical reference architecture based on RaMicsV. Some implementation details of microservices within this architecture follow in Section VI. Section VII concludes and looks at future work.

II. Related Work

The foundations of this work relate to the concepts of Microservices Architecture, cloud computing, cloud-native architecture, and practical application within the insurance industry.

Our research builds on authors in the field of microservices, such as the work of Newman [12], as well as Fowler and Lewis [2], as well as Fachat [13]. When designing our reference architecture, we benefit from various microservices patterns discussed by Richardson [14].

To design T-RaMicsV, we use a cloud-native approach that is definitionally based on the descriptions of the Cloud Native Computing Foundation [15]. Furthermore, we supplement our understanding with the aspects of cloud computing introduced by the National Institute of Standards and Technology (*NIST*) [16], as well as containerization, automation, and observability. We also used works by S. Reinheimer to learn the basics of the cloud. [17]

To implement the approach in practice, we are using an exemplary insurance industry business process. For this purpose, we have chosen car insurance, one of the core products of German insurers. The authors [18] provide the basis for the process. Car insurance is compulsory for every car in Germany. For this reason, it is considered particularly important for acquiring new customers. The elaboration refers to the VAA [19] and describes in detail what car insurance is all about and much more. We use Business Process Model and Notation (BPMN) to realize the processes [20], as it is widely used in the insurance industry.

In this contribution, we lay out T-RaMicsV that is derived from RaMicsV [21] as our foundation. An implementation of RaMicsV that demonstrates its technical feasibility, as envisaged in this paper, has not yet taken place.

Regarding its realization, a technical reference architecture must be developed that makes fundamental statements about the technologies used, such as programming languages or infrastructure. In accordance to Angelov, Grefen, and Greefhorst [22] T-RaMicsV can be categorized as a 'semi-concrete type 4' reference architecture, i.e., indicating technology choices to be implemented in one single organization [22].

In this context, the technology-agnostic approach of microservices is broken with, to provide practical specifications that harmonize with the existing system landscape of an insurance company. The cloud-native approach used in this contribution is a conceivable option that seems promising to us to realize RaMicsV technically.

Deriving a technical reference architecture from a logical one, like RaMicsV, seems to be a common practice. Furthermore, there are contributions to reference architecture for microservices for broader enterprise context, e.g., by Yu, Silveira, and Sundaram in [23]. However, this has not yet been done for insurance companies such as our industry partners and their specific requirements.

These operate a historically grown heterogeneous system landscape characterized by an existing SOA. The use of microservices, that is embedded in the cloud-native approach, must be integrated in a cooperative manner, which plays an essential role in our overall architectural considerations.

III. Service-based Reference Architecture for Insurance Companies

This section presents our RaMicsV as initially started in [9].

RaMicsV defines the setting for the architecture and the design of a microservices-based application for our industry partners. The application's architecture will only be shown briefly, as it heavily depends on the specific functional requirements.

When designing RaMicsV, a wide range of restrictions and requirements given by the insurance company's IT management have to be considered. Regarding this contribution, the most relevant are:

- Enterprise Service Bus (ESB): The ESB as part of the SOA must not be questioned. It is part of a successfully operated SOA landscape, which seems suitable for our industry partners for several years. Thus, from their perspective, the Microservices Architecture (MSA) style is only appropriate as an additional enhancement and only

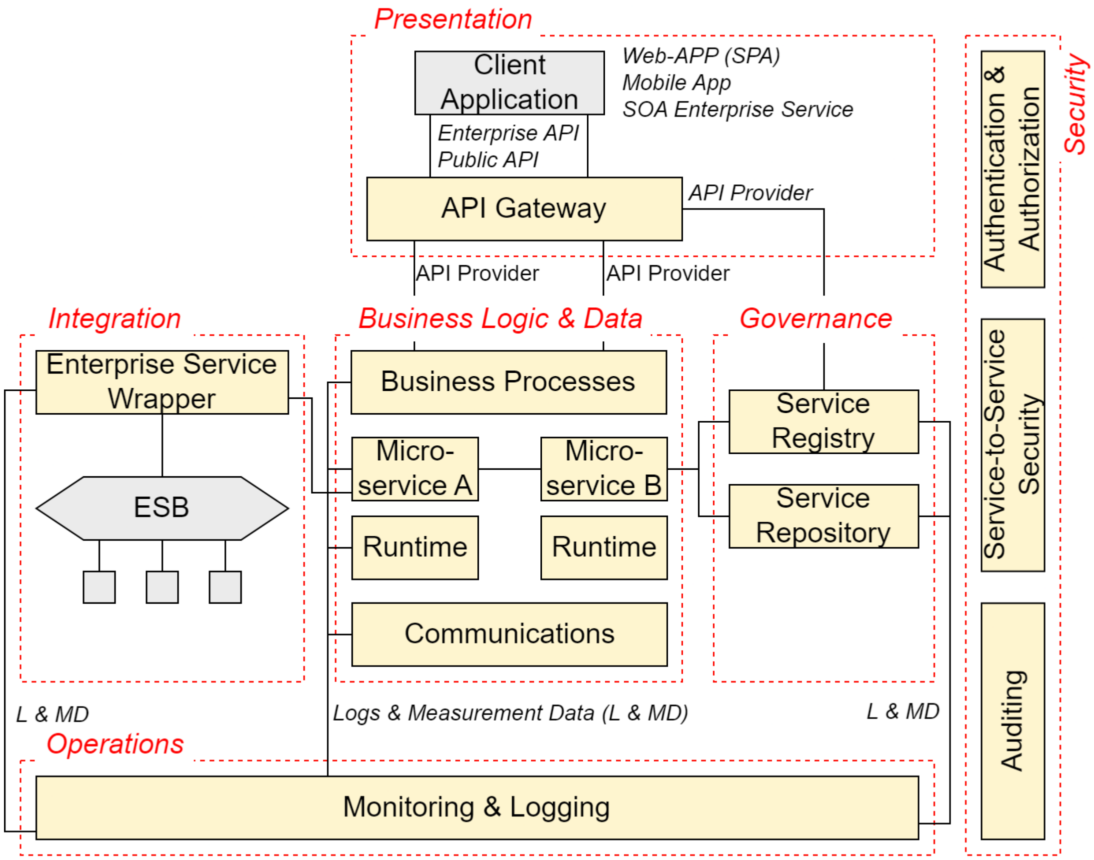

Figure 1. Building Blocks of the Logical Reference Architecture RaMicsV.

a partial replacement of parts from their SOA or other self-developed applications.

- Coexistence: Legacy applications, SOA, and microservices-based applications will be operated in parallel for an extended transition period. This means that RaMicsV must provide approaches for integrating applications from different architecture paradigms – looking at it from a high-level perspective, allowing an 'MSA style best-of-breed' approach at the enterprise architectural level as well.
- Business processes are critical elements in an insurance company's application landscape. To keep their competitive edge, the enterprise must change their processes flexibly and agilely. RaMicsV must, therefore, provide suitable solutions to implement workflows while ensuring the required flexibility and agility.

Figure 1 depicts the building blocks of RaMicsV, which comprises layers, components, interfaces, and communication relationships. Components of the reference architecture are colored yellow; those out of scope are greyed out.

A component may be assigned to one of the following *responsibility areas*:

- **Presentation** includes components for connecting clients and external applications, such as SOA services.
- **Business Logic & Data** deals with the implementation of an insurance company's processes and their mapping to microservices, using various workflow approaches to achieve desired application-specific behavior.
- **Governance** consists of components that contribute to meeting the IT governance requirements of our industrial partners.
- **Integration** contains system components to integrate microservices-based applications into the industrial partner's application landscape.
- **Operations** consist of system components to produce unified monitoring, logging, and tracing, which encloses all systems of the application landscape.
- **Security** consists of components to provide the goals of information security, i.e., confidentiality, integrity, availability, privacy, authenticity & trustworthiness, nonrepudiation, accountability, and auditability.

Components communicate either via HTTP(S) – using a RESTful API, or message-based – using a Message-Oriented Middleware (MOM) or the ESB. The ESB is part of the integration responsibility area, which itself contains a message broker (see Figure 1).

In the next section, we will present our understanding of cloud-native architecture, which represents our approach to developing T-RaMicsV as this paper's contribution.

IV. Cloud-native Architecture

The architectural approach of our contribution is based on the following five aspects of a cloud-native architecture.

- **Cloud Computing** means that an IT service is offered by a cloud service provider and used by a cloud service consumer. The NIST [16] defines Cloud Computing via five **characteristics**: *On-demand self-service*, *broad network access*, *resource pooling*, *rapid elasticity*, and *measured service*. Different **deployment models** (*Public*, *Private*, *Community*, and *Hybrid*) are used to describe ownership and control of the cloud environment, while **service models** describe the level of abstraction from a consumer perspective (*Software-*, *Function-*, *Platform-*, *Container-*, and *Infrastructure as a Service*. They are abbreviated to SaaS, FaaS, PaaS, CaaS, and IaaS, respectively). CaaS and FaaS are often used in the industry.
- **Microservices** are considered – clearly not the only – but the 'most native' architectural style in cloud-native architectures. They grant loose coupling as well as independent scaling and deployment [14]. These services are modeled around business functionality and gain high cohesion in the process.
- **Containerization** is the process of deploying software for a cloud-native architecture as isolated, virtualized units. Containers offer efficient hardware usage and dynamic resource allocation.
- **Automation** in a cloud-native architecture aims at automated deployments of microservices and new functionality. To achieve this goal, concepts like Continuous Integration and Continuous Deployment (CI/CD) [12] and Infrastructure as Code (IaC) [24] play a vital role.
- **Observability** is the aggregation and analysis of data in a system to gain transparency and understanding about the internal components [25]. This supports troubleshooting in a microservices-based system, where data and business logic are distributed [12].

The following section will provide insight into our cloud-native technical reference architecture, designed with our business partners in mind.

V. Cloud-native Technical Reference Architecture for Insurance Companies

This section provides an overview of T-RaMicsV (see Figure 2). It has been designed using a cloud-native approach, which is expected to provide good scalability, short release cycles, and high resilience.

T-RaMicsV provides for private cloud and public cloud as the underlying operating model. The host machines of all elements of the architecture are physical or virtual machines, whereby the former can also include mainframes typical for Insurance Companies. In line with the cloud operating model, the host machines are operated in the company's data center or booked as IaaS solutions from public cloud service providers. A hybrid cloud scenario is also made possible by T-RaMicsV. In the insurance context, for example, it would be conceivable to use only certain IT services in the public cloud while continuing to process highly regulated, sensitive customer data in the company's own data center.

The chosen cloud-native approach implies the operation of microservices as containerized workloads. Thus, a central element of the reference architecture is the container orchestration platform (COP). It is operated by the company itself or purchased as a managed service from a public cloud provider. All microservices and their databases, the Enterprise Service Wrapper (ESW), a MoM for message-driven communication, and the Security Token Service (STS) are operated in containers. These run in a container runtime environment managed by the container orchestration platform, which also distributes them across multiple host machines. A microservice is horizontally scaled in an automated fashion by the platform as a set of containers, where one container corresponds to one service instance.

Furthermore, the platform performs the task of service discovery, i.e., a mechanism by which the microservices of the architecture can find and address each other. In addition, the COP provides routing capabilities and allows load balancing between multiple instances of a microservice.

The MSA includes business-oriented microservices, named A to C, as examples in Figure 2. These mainly communicate in an asynchronous, message-driven fashion via topics or queues provided by the MoM. Depending on persistence needs, a microservice may exclusively use its own database.

For authentication and authorization purposes, microservices exchange JSON Web Tokens (JWT) with each other as security tokens. These are issued by the STS of the architecture, to which the microservices must authenticate themselves. In addition to the use of JWT, T-RaMicsV stipulates that microservices communicate with each other in an mTLS-encrypted form.

To gain transparency in the architecture, metrics, logs, and traces of the services are collected. These can be aggregated, processed, and analyzed in corresponding solutions.

As in correspondence with RaMicsV, the SOA with ESB is understood as an existing system landscape part in T-RaMicsV, in which existing SOA services are operated. The connection to the ESB is a classic use case in the context of insurance. The legacy systems characterized by SOA cannot be replaced by microservices but should instead be extended. The insurance partners are aiming for the coexistence of SOA and microservices.

In the insurance industry, for example, SOAP — or REST-based web services, Enterprise Java Beans (EJB), or SAP systems offered as SOA services are conceivable. The SOA with ESB is run on host machines in the company's own data center but not on the container orchestration platform. The Microservices Architecture on the COP is considered a part of the landscape in which new services can be realized

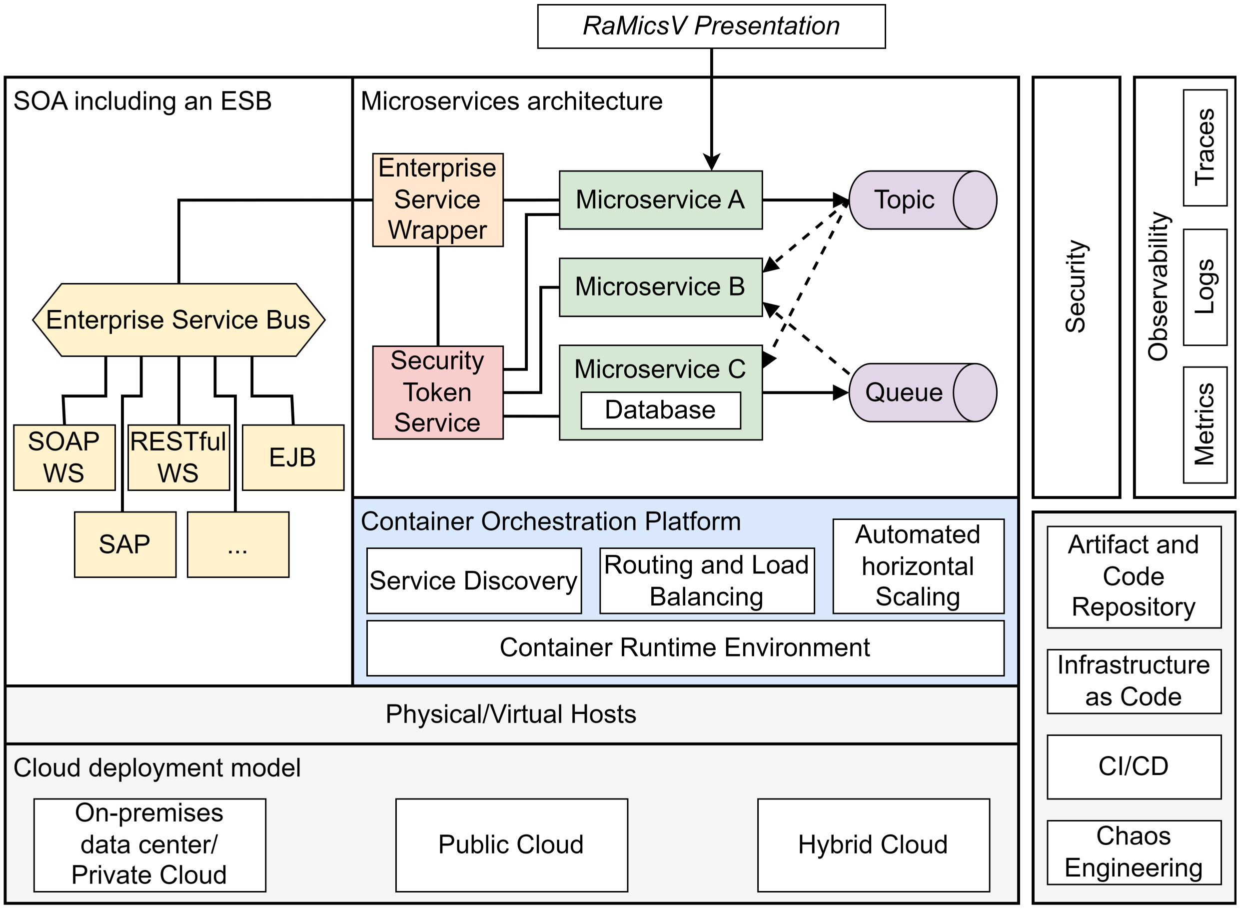

Fig. 2. Building Blocks of the Technical Reference Architecture T-RaMicsV.

as microservices. Existing SOA services could be migrated successively to the Microservices Architecture as required.

T-RaMicsV provides a proposal for the ESW, a component directly derived from RaMicsV. The ESW acts as a central transition from the Microservices Architecture to the ESB of the SOA. It is accessed by one or more microservices via REST when they need to consume a SOA service.

The software delivery process is planned to be automated as much as possible. For this purpose, CI/CD pipelines are used to build, test, and deliver artifacts. Provisioning of virtual infrastructure, especially the one provided by a public cloud service, should be based on the IaC principle. The infrastructure and application code, as well as the software artifacts, are captured and versioned in appropriate repositories. With the aim of increasing the resilience of the Microservices Architecture in production, it may additionally be tested using Chaos Engineering methods.

In the following, we give an overview of a concrete implementation example of our proposed technical reference architecture and shed light on more details.

VI. Cloud-native Microservices

This section presents the more specific design of microservices in T-RaMicsV, together with an overview of an implementation example of the proposed approach (see Figure 3). It was operated in the eduDScloud, a private cloud used for academic and educational purposes [26].

The example implements a part of a typical business process in the insurance industry we modeled, called the *Car Insurance Process* (from [18]). In this process, a customer submits an application to an insurance company to successfully conclude a contract for a car insurance policy. The workflow in this example is realized by the four business-oriented microservices `insurability`, `application`, `premium`, and `policy`.

To achieve high availability of the microservices, asynchronous communication over a MoM is preferred, and synchronous calls are to be reduced to a minimum. For this purpose, a solution like Apache Kafka can be used to implement messaging. The synchronous communication style is implemented as REST calls in combination with JSON as the serialization format. It is a common and well-understood synchronous inter-process communication style between microservices.

The ESW is implemented as a technical microservice (`eswrapper`) that propagates calls from the MSA to the ESB of the SOA. The ESB, in turn, consumes a SOA service, which can be a SOAP web service, as shown in the example (`solvency`). The JWT that the microservices use for authen-

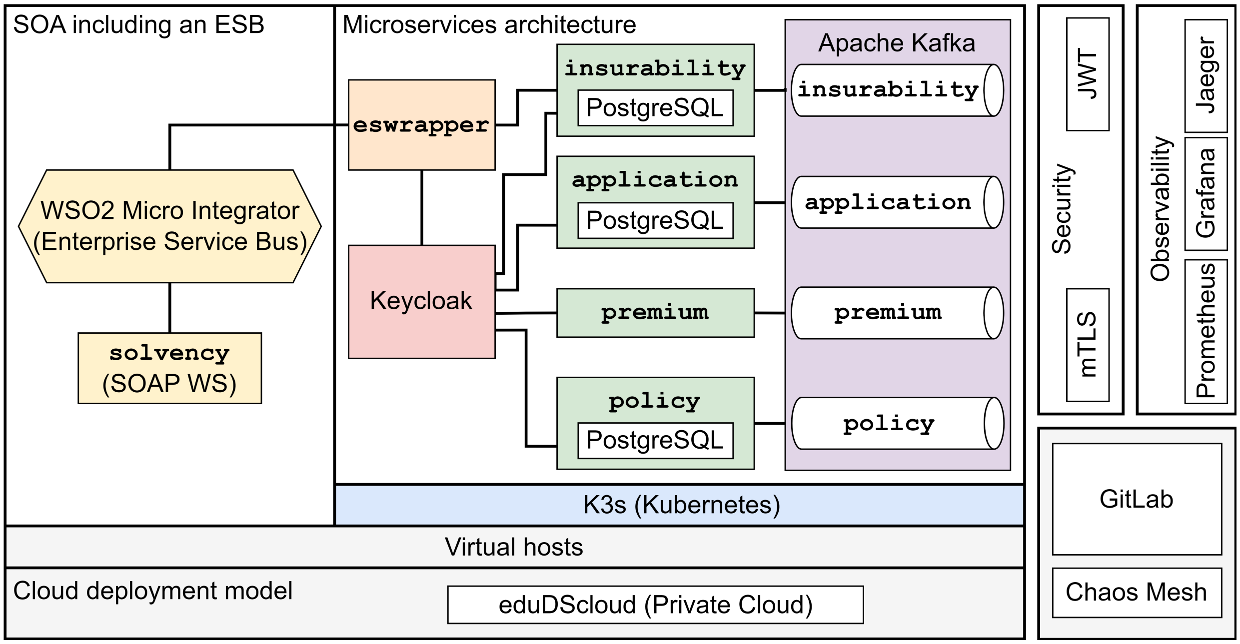

Fig. 3. Technical Architecture for the *Car Insurance Process*.

tication and authorization purposes are issued by Keycloak in the role of the STS.

A. Event-driven Choreography

In continuation of our previous work in [11] and [27], choreography is preferred over orchestration in T-RaMicsV to realize business processes through a microservices-based architecture. Furthermore, event-driven communication is proposed to implement the choreography. This approach supports loose coupling of microservices and enables good scalability of the architecture. The complexity caused by the implicit communication of the microservices of this approach has to be addressed by observability solutions, e.g., Prometheus and Jaeger with Grafana, for visualization purposes.

The publication of events is carried out according to the *publish-subscribe* pattern. A service emits events according to the *fire-and-forget* principle in a topic managed by the MoM. Interested services can subscribe to the topic, receiving the corresponding events, whereas the publishing service has no knowledge or expectation of whether or not the events are processed. The choreography then emerges as an interplay of publishing events and responding to those events.

The MoM only plays the role of a mediator that forwards the events. It is not meant as an orchestrator in the sense of orchestrating services since it does not include any logic to control or monitor the business-oriented correctness of the communication flow.

B. Scalability

The scalability of microservices in T-RaMicsV is considered using Newman's extended scaling cube [12]. Scaling is based on the dimensions of functional decomposition into microservices and horizontal scaling of these services through replication. The functional decomposition of a domain into microservices is derived directly from RaMicsV and is an essential component of the chosen cloud-native approach. Horizontal scaling is achieved by running the microservices in containers.

A container serves as a lightweight delivery unit that provides a consistent, isolated environment for the microservice and can be updated independently of other containers. The containers can be distributed and moved virtually without much effort. This results in the potential for more efficient utilization of hardware resources and higher availability.

Replication of a microservice into multiple instances can be achieved by various provisioning of a corresponding container. This and the management of the instances in the form of the individual containers is handled by the container orchestration platform. The platform also provides the mechanism for load balancing and routing requests to a group of replicas of a microservice. An often used platform for this is Kubernetes, available in different distributions, like K3s, which was used in the example (see Figure 3).

The dimensions of data partitioning and vertical scaling are not considered in a focused manner by T-RaMicsV. In the case of data partitioning, it should be mentioned that concrete DBMS products that can be used in principle may implement internal mechanisms of data partitioning. For example, consider the document-oriented DBMS MongoDB, which implements data partitioning via its sharding technology [28]. The elasticity of the Microservices Architecture is addressed by horizontal scaling of the services.

This must take place in an automated manner, depending on the generated load. This is the responsibility of the container orchestration platform, which offers a corresponding mechanism for automating the horizontal scaling of the services. Depending on the workload on the existing containers, new ones are started up, or existing ones are terminated again when they run idle.

The availability of a service can be supported by horizontal scaling. A service remains available overall, despite the failure of individual instances, as long as a correspondingly high number of replicas is provided that is ready to respond to queries.

C. Fault tolerance

The distribution of the containers across different virtual or physical host machines managed by the COP is significant for the overall consideration of resilience. If all instances of a microservice were running on the same host machine and that machine was to fail, the service would not be accessible despite replication. The same applies further if the COP is run on virtual machines and these are only deployed on one physical one.

The virtual machines must be distributed across multiple physical ones. The distribution of the virtual host machines to multiple physical ones is outside the responsibility of the container orchestration platform, as it does not differentiate between physical and virtual host machines. This must be handled by the underlying virtualization solution.

D. Delivery

The container orchestration platform is responsible for managing a highly dynamic environment that results from continuous shutdown and startup of different containers. This is done intentionally, e.g., by new releases of services, or unintentionally, e.g., in case of failure.

To be resource-efficient and minimize the time to boot up containers, lightweight software artifacts should be targeted. Thus, a container image of a microservice should always be designed with a 'just as much as necessary' approach in mind. A lightweight operating system and only the packages, libraries, and files required for the service running in the container should be included in the image.

The infrastructure should be provided according to the IaC principle, especially when using public cloud services, and configured as immutable infrastructure only via the code. The infrastructure code can be recorded in version management systems, such as Git, and hosted with solutions like GitHub or GitLab, as used in the example. It thus serves as the *Single source of truth* of the infrastructure and can be versioned like application code. This creates transparency among administrators and developers and enables traceable, repeatedly executable deployment. In particular, in the event of a failure, this approach allows the system to be reliably recovered.

The application and infrastructure code of different microservices should be managed separately in their respective repositories. This can lead to redundant code between the repositories of different microservices. However, to support the autonomy and loose coupling of the microservices, this is recommended, especially regarding different development teams working on each of them. In this context, a platform like GitLab can also be used to implement CI/CD pipelines to automate the delivery process.

VII. Conclusion and Future Work

In this contribution, we present a cloud-native-based technical reference architecture that aims to build compliant microservices-based applications for insurance companies. The architecture adopts our partner's special requirements, such as integrating SOA services.

The reference architecture is applied to the car insurance process to shape an application-specific architecture for this scenario. With the given selection of specific technology, we present an instance of one possible implementation of our technical reference architecture.

The following steps in our research work are the integration of Microsoft Azure as a prominent public cloud solution (see block 'Cloud deployment model,' Figure 2). Again, the Car Insurance Process will be used to build a conforming architecture. The findings may require enhancing or even redesigning our technical reference architecture.

In the following work, we will carry out experiments on the technical reference architecture using chaos engineering. We will focus on requirements such as scalability. We are also investigating the topic of security in the context of microservices using homomorphic encryption within cloud environments.

Another topic is the refinement of the building block Business Processes within the responsibility area Business Logic & Data (see Figure 1). Choreography is the preferred approach to implementing workflows. Based on BPMN Choreography diagrams, we identified and classified frequently occurring patterns in the context of the insurance industry. Our goal is to implement the patterns to make choreography diagrams executable.

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Predicting the Acceptability of AI and Robots among Education and Healthcare Professionals with the Revised 4-A Model

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***Abstract*—Currently, Artificial Intelligence (AI) and robotics systems are considered as two major disruptive technologies in healthcare and education. Acceptability and acceptance of AI and robotic systems are crucial for an effective use. Because the increasing use of digital technologies, such as artificial intelligence (AI) and robotics system may be harmful to professions and occupations, it is crucial to investigate the relationships between professional identity towards robotics systems to describe and predict the acceptability. In this paper, we present a revised version of the 4-A model (for Acceptability, Acceptation, Approval, Appropriation) to apprehend the relationships between professional identity and acceptability. The origins and the main advantages of this revised theoretical framework are presented and discussed. This paper contributes to efforts to shift the ways in which the future of work and the rise of robotics and AI are understood by proposing a new framework for articulating the resulting disruptions in relation with professional identity.**

***Index Terms*—Professional identity; Artificial intelligence; Robotics, Acceptability; Health; Education**

I. INTRODUCTION

This paper is aiming to present the revised, extended and the more recent version of the 4-A model integrating the different components of the professional identity to better describe and predict the acceptability of technology [1], such as robotics systems and Artificial System. The first section is presenting the relationships between acceptability and professional identity before to discuss the links between acceptability and ethics in professional context, specially when robotics systems are used. The second section is focused on the revised 4-A model, by presenting its advantages and its implication and the integration of the different components of the professional identity on acceptability.

A. Acceptability of AI and Robot in the Real Professional Context

Automation, the replacement of people in the workplace by machines is not something new, but digital technology, such as robotics systems and AI have increased the capabilities of these machines enormously. There have been significant developments in social robotics in the care sector, in particular, in the fields of elder care and in the care and education of children and young people, especially those with specific disabling conditions, such as autism. With the rapid development of technology, have humans come to regard robots as their competitors? If so, how has this perception affected human–robot interactions? [2]

The increasing use of digital technologies, such as Artificial Intelligence (AI) and robotics system may be harmful to professions and occupations. Professional role identity can be damaged as AI and robots take the place of people across a broad range of professional tasks. As increasing numbers of social robots are developed, tested and deployed, attention is shifting towards issues of user experience [or UX] – including how robots are 'accepted' by users [3] [4].

This has become both a practical and an ethical issue. On the one hand, people are probably more likely to make use of, or live with, robots if they feel comfortable with, or even like, them. On the other hand, there are important ethical issues in relation to autonomy, choice and power when it comes to introducing robots to workplaces, care settings or domestic spaces. The socially or physically vulnerable, for example, should not be coerced into interacting with robots in the place of humans. Some authors calls our attention to the potentially two-sided nature of Human-Robot Interaction (HRI). Robots can be caregivers of humans; but humans can also be the caregivers of robots [5].

The acceptability (judgement before use) of a new technology, such as a robot, could involve multiple, diverse factors. The most commonly used model to describe and predict acceptability is Nielsen's model [6], which is mainly structured around practical acceptability and usefulness. Usefulness is the degree in which a person trusts the technology to perform the desired goal, and in Nielsen's model is broken down in two further notions: Utility and Usability (Figure 1).

More recent predictive theories of technology, such as the Technology Acceptance Model (TAM; Davis [7]) or the Unified Theory of Acceptance and Use of Technology (UTAUT [7] [8] [9] [10]), are also based on a priori studies. Some more recent research in Informative Sciences, based on acceptability, focus progressively on real use and adoption [10]. The emerging theory of 'situated' acceptability proposes to consider four dimensions (individual, organizational, relational, professional/identity) of the occupational activity in the field of social psychology [11] [12], and explains how acceptability factors should be engineered by confronting a real professional context. Unfortunately, little research has been reported on acceptability – the judgment towards a product after use – where both functional and perceptive factors are studied during first use (familiarization phase). Moreover, whatever the technology considered, existing models of acceptability, essentially based on predictive methods and information sciences, were not considered relevant for the case of occupational robotics in real setting, such as educational settings or in the care sector [13] [14] [15].

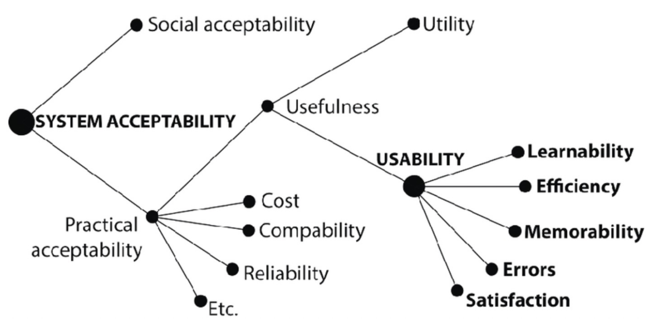

Figure 1. Nielsen's model of system acceptability.

Finally, all these existing models (e.g., Nielsen's model, TAM, UTAUT) are used to study mature and similar informative technologies, whereas innovative devices, such as robots, change the framework of acceptability through a new user-product relationship [13]. Moreover, some appropriation theories in activity ergonomics explain that it is the actual experience of the product that will influence future behavior and future adoption [16]. In addition, the acceptability of digital systems needs to consider physical and environmental aspects. This consideration of interfacing is why we believe that existing models of acceptability are not sufficiently adapted to physical user-product experience in the occupational environment.

Consequently, there is a need to involve real work situations to identify important determinants of robot acceptability, and a more holistic and usability focused approach is needed to identify obstacles to social worker acceptability that are not evident in a laboratory environment (e.g., [17]), in particular if we want to better understand the influence of robotics systems on professional identity.

B. Acceptability, Ethics and Professional Identity

How will the future world of the social care professional and education, specially for users with specific needs, evolve in this context? What will the acceptability of social robots be amongst social professionals who have different professional identities?

Professional identities refer to the way we define ourselves in relation to our work, including the values, beliefs, and practices that shape our sense of professional self. It is a complex and multifaceted concept with significant implications for both individuals and organizations. In recent years, there has been a growing interest in the study of professional identities in the healthcare and education professions (e.g., [18]). Professional identity is a crucial construct [19] that impacts many important aspects of individuals' lives such as:

- Confidence in advocating for professional opinion;
- Source of meaningfulness;
- A sense of self-worth and empowerment;
- Determination of one's moral decision-making and behavior;
- Psychological well-being.

Teachers psychological empowerment tends to be an important factor of their professional identity. It refers to teachers' confidence in their ability to do their jobs well and their belief that their work is meaningful and valuable. Teacher professional identity is seen as a sense of recognition that teachers have for the profession of teaching. In fact, Sun et al. [20] indicate that teachers with higher level of recognition of their profession will believe that their work is more meaningful and valuable. That is, they will have a higher level of psychological empowerment. Specifically, the higher the level of teachers' professional identity, the higher their psychological empowerment will be, which will lead to increased work engagement. Therefore, teachers can fully dedicate themselves to their work when they have a professional identity in terms of the profession of "teacher", which will improve their professional identity. In this way, Ding et al. [21] indicate that both psychological empowerment and professional identity were significantly and negatively related to work burnout, and psychological empowerment was significantly and positively related to professional identity.

For instance and as Figure 2 shows, the same robot and AI in a classroom can have diverse uses to improve the learning of science. In the same way, and as Figure 3 shows, to meet the needs of autistic children, the use of a robot has increased over the years. Studies [22][23][24] point to benefits in the development of academic skills and social interaction. It appears that most children with ASD prefer to interact with robots because of their simplicity, and predictability. Indeed, the emotional microexpressions, behavioral variations and different voice intonations of professionals can be obstacles to understanding autistic children. However, the results of the studies cannot be systematized, as the profiles of the children and the robots used differ from one study to another. Whatever the context (Figure 2 or Figure 3), the acceptability and the use of the robotics systems are strongly related to the professional identity of the teachers or the educators.

Some are objects of study for students to practice programming, others are tools which assist a teacher, some can be learning companions, and others might be autonomous teachers which provide some unit of instruction more or less in its entirely. Like most innovations, there may be a good side and a bad side, and care is needed to foster the former and counter the latter. The roles of the human teacher change over time with needs, new tools and teaching aids, but the capabilities and nature of AI promote teaching robots to new levels of relationship with the teacher and the learner as Figure 2 shows. Aids to teaching and learning are not, of course, new. Humanoid robots, however, are more active, even pro-active. Unlike the passive textbook, they can respond and adapt to each student, tailoring teaching to particular needs. There is clear evidence that they have the potential to support learning, as in teaching children about their medical conditions, developing and rehearsing learning, and testing it. Finally, robots can even do what a teacher would find difficult by his or her presence, as in teaching an ASD student while slowly accustoming that student to social interaction [25].

Identity is generally the concept that defines who a person is in relation to some phenomena, groups, objects, and social behaviors [25]. Material objects, personal characteristics, or group norms can be an integral part of identity if individuals use them to identify themselves in communities [26]. Identity has mainly been studied from two perspectives: collective and individual level. At the collective level, social identity is framed based on membership in a social group, the group's values and the culture.

Profession is one of the most important social categories [28], and professional identity is a particular form of social identity in professional settings [29]. It is 'an individual's self-definition as a member of a profession and is associated with the enactment of a professional role' [30]. As the definition suggests, enacting a particular role is an essential part of one's professional identity. This role enactment also gives rise to role identity [31] [32]—'the goals, values, beliefs, norms, interaction styles, and time horizons that are typically associated with a role' that provide a 'definition of self-in-role' [31]. Therefore, professional identity is inherently centred around professional role identity. Moreover, evolution of values, representations and interactions over time makes identity evolutionary and dynamic.

C. Professional Identity, AI and Robotics

Appriou Ledesma [33] developed the concept of identity strategies as characteristic of a dynamic at work in adult training in France. According to Camilleri et al. [34], identity strategies are then understood as "procedures implemented (consciously or unconsciously) by an actor (individual or collective) to achieve one, or more, goals (explicitly defined or situated at the unconscious level), procedures developed as a function of the different determinations (sociohistorical, cultural, psychological) of this situation". The functioning of identity strategies thus induces a process that evolves according to the interactions experienced, the objectives pursued and the search for integration into a group, recognition (in this case professional recognition) or even self-esteem [33]. It is made up of inseparably complementary and conflicting components. It includes inherited, acquired and projected identities whose construction, in social interaction with others, generates tensions. These tensions thus lead the subject to implement identity strategies whose "objective is to safeguard the integrity of the identity, maintain the coherence of its various components, as well as guarantee the authenticity of the project of oneself for oneself (identity project)" [33]. The practical training of a professional, invested in a mission and driven by a mandate (and a professional contract), leads him or her to deploy unfixed strategies in order to exercise his or her professional identity, through precise conducts and mechanisms. Depending on one's position and relationship with others, the establishment of one's professional representation will involve strategies aimed at ensuring consistency with one's initial training or, on the contrary, at extending the shared space of common representation.

Recognized as useful worldwide, Karasek's model [35] affirms the occurrence of illnesses linked to perceived stress at work and caused by potential identitary tensions [36]. He studied work-related stress in two axes: the demand (or professional constraint or workload) and the individual's control (or decision latitude or leeway) over his or her work. He hypothesizes that stress arises in work situations that high work demands (a heavy workload) and low control over them. It thus highlights the importance of assessing professionals' representation of work. To explore this idea further, Cappe et al. [37] present in their study an investigation into burnout among educators working with people with autism. The results shows the existence of increased stress in the practice of accompanying autistic people. The feeling of ineffectiveness and incompetence appears to be prevalent in the face of care difficulties. The latter is amplified among professionals who feel they have received less training than their colleagues.

Many aspects impact professional identity. Therefore, this point can be weakened by robot integration. In fact, as robots can be anthropomorphized, a cognitive bias can appear, such as social comparison. Anthropomorphism is assigning human-like traits, emotions, and behaviors to non-human entities. As a result, the perception of self-worth, confidence, and psychological well-being are impacted because employee's comparison implies that robots can replace themselves. Robot anthropomorphism can influence employees' perception of their job insecurity in work situations. This feeling of insecurity is sometimes created by employees' comparison due to anthropomorphic thinking and can impact professional identity in work situations.

Not surprisingly, different viewpoints exist across culture [38]. Moreover, very few authors have investigated the relationships between professional identities and acceptability of robotics systems [39]. For instance:

- Cahill et al. [40] highlighted that available technology had been successfully integrated into the care plans of patients in Ireland, but caregivers perceived it to be prohibitively expensive;
- Wolbring and Yumakulov [41] reveal that staff in a Canadian disability organisation are content to work with social robots as long as they perform repetitive tasks that:

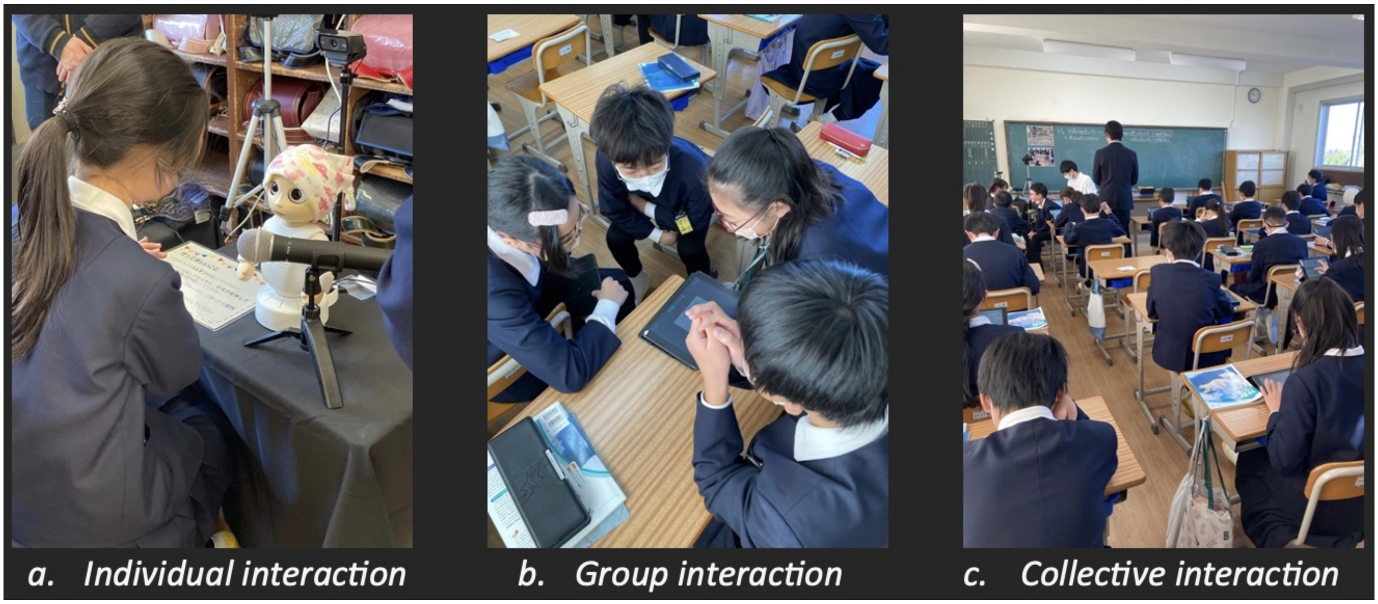

Figure 2. The use of a robot and IA to improve science learning in a classroom: the different contexts from personal, group and collective interactions [26] [27]

Figure 3. The use of a robot with a young child with Autism Spectrum Disorder (ASD)

"did not require mimicking human interaction and touch" (p. 465);
- Conti et al. [42] provide insights into the acceptability of robots in the education and care of children in Italy, uncovering that established practitioners are largely skeptical of such innovations, while less experienced degree students in psychology and education demonstrate a "significantly higher willingness to use" robots. Pragmatically, they find that "intention to use" a (hypothetical) robot is "mainly predicted by the perception that it will enhance and facilitate the educational process". Moreover, they report that "practitioners have a clearer view than students of the educational and therapeutic tools available and their effectiveness. They can easily identify the current technology difficulties and limitations" (including cost).

Working with, alongside or even for robots will have significant implications for social professional practice and identity. Practitioners may benefit from the opportunity to engage with and, if deemed appropriate, develop the skills required to work in collaboration with social robots. Those involved in the education and formation of the social professionals of the future have an obligation to stimulate and facilitate debate that may, as a parallel outcome, lead to debates about the broader philosophical, ethical, social and practical nature of 'care' itself.

D. Technology and Professional/Occupational Role Identity Change

Among the various drivers of social change, technology has long been considered an essential factor in professional settings [43]. It has recently become still more vital due to the increasing impact of digital technology on professions and occupations [44] [45]. However, as Goto says [28], studies on professional and occupational role identity have rarely investigated the impact of technology.

New technology does not enter an occupational field fully defined but is constituted within the context [46] [47]. As such, technology has a way of influencing professional and occupational identity through a peculiar mechanism. Past studies have highlighted three important aspects of this mechanism.

- individual-/group-level studies have revealed that new technology itself can trigger professional and occupational identity reconfiguration and give rise to a new identity through professionals' new practices and boundary negotiations with others;
- Very few researchers have addressed the collective-level identity shift;
- Only some studies have implied that the implementation of new technology, such as robot among professionals may have an important link with the shift of professional identity;

The impact of the implementation of artificial intelligence (AI) on workers' experiences remains under-examined. Although AI-enhanced processes can benefit workers (e.g., by assisting with exhausting or dangerous tasks), they can also elicit psychological harm (e.g., by causing job loss or degrading work quality) [48][49]. More precisely, recent studies revealed three central predictors for AI identity threat in the workplace: changes to work, loss of status position, and AI identity predicting AI identity threats [50]. In the same way, because the integration of AI in an organization affects recruitment, training, performance management, and employee engagement, influencing job satisfaction and work-life balance, surveys revealed that both workers and employers generally view AI positively for improving performance and working conditions, but there are lingering worries about job loss and the need to enhance trust through training and worker consultation [49][51].

A recent framework has been created by [48] to better understand and examine "how changes and challenges associated with AI implementation can be understood using this functional-identity framework. The introduction (or anticipated introduction) of a nonhuman 'intelligent' actor demands sensemaking, which will affect how workers think about themselves and experience their work—generating opportunities for both work-related identity threat and work-related identity enhancement, with subsequent effects on well-being, behavior, and attitudes". Figure 4 presents this recent framework.

II. The Revised 4-A Model: Acceptability, Acceptation, Approval, Appropriation

As Figure 5 shows, the actual 4-A model based on [27] [26] is an innovative model providing an explanation of the temporal process of appropriation of a digital device, such as a robot (for a complete presentation of the model, see [26] [27]. Emerging technology is not an identity threat per-se, and the relation between human and robot, regardless the professional identity, need to clarify the dependence between these two partners (either partnership, or master-slave).

A. Origins of the 4-A Model

Several studies related to the TAM theory [52] [53] [54] or the UTAUT theory [8] [9] [7] describe the role of professional identity on future acceptability and acceptance of digital devices [52] [53] [54]. But even if all these prior studies related to TAM or UTAUT theories provide very interesting results, they have four important limitations that prevent to generalize results:

- Data are often collected by using questionnaires and surveys, i.e., only attitudes, opinions and verbalization are collected;
- Data are often collected during only one-shot setting, and thus do not investigate the longitudinal and temporal process of appropriation across the time;
- They assume that the effective use of a digital device means that this device is accepted;
- Professional context and environments (physical and social) are rarely considered.

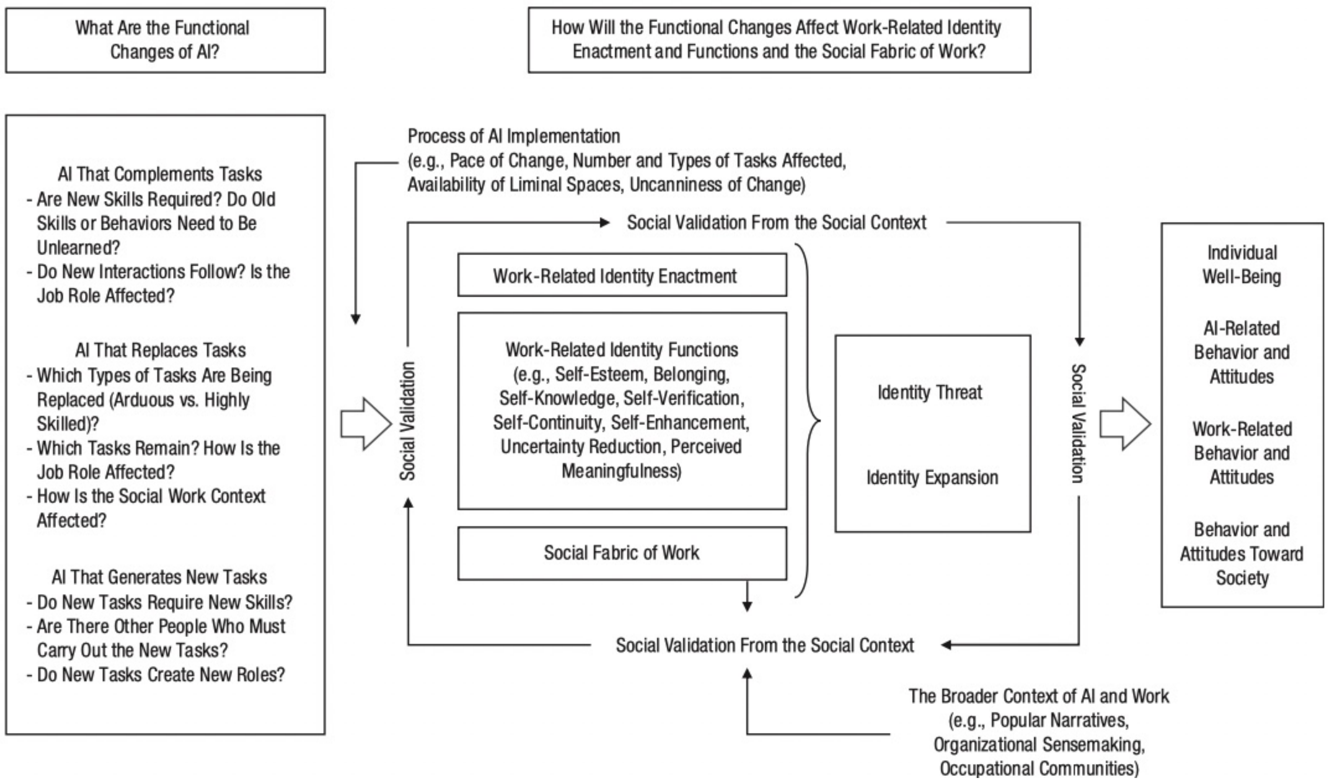

Figure 4. The framework to understand the impact of AI and robotics on work-related identity according to [48]

It is the reason why a new model has been created (called 4-A for "Acceptability, Acceptation, Adoption, and Appropriation") to better describe and predict the complex processes involved from the acceptability to the effective use of digital technology and to better understand the relationships with the professional identity.

If there is consensus in the research that professional identity is a multidimensional concept, it's still no unanimous agreement on its central components [55][56][57]. Be as it may, in addition to the first version of the 4-A Model, we added four components that have emerged from a variety of studies as manifestations of professional identity in healthcare and education (Figure 5).

B. The 4Model: its Advantages and its Implications

The 4-A model has several advantages:

- This 4-A model (Figure 5) allows to better understand the relationships between attitudes, opinions and effective behaviours;
- If attitudes can determine behaviours (as other theoretical frameworks argue), the 44 model states that behaviours can influence attitudes by retro-feedback;
- In the 4-A model, the temporal and longitudinal dimensions related to the appropriation are included by distinguishing before and after the implementation of the device in the context. So, dynamics of the human behaviours is crucial in the 4-A model, by considering that attitudes and behaviours can change across the time;
- In the same way, there is a remarkable amount of variation in the beliefs, attitudes, professional identity and values held by people around the world. These views are often cultural, meaning that they are, at least to some extent, socially learned and socially transmitted. They are often shaped by tradition; namely, this transmission and persistence of cultural values across generations are captured by the 4-A model;
- The use of a device, such as a robot, does not necessarily mean that this device is approved and accepted because individual can be forced to use the device. It is the reason why two types of use are distinguished in the 4-A model: Approved use (i.e., where individual is agree to use freely and.or s/he can be convinced) versus Forced use (i.e., where individual is obliged to use the device for instance, by his/her hierarchy). In other words, according to the 4-A model, an effective use of a device does not necessarily mean that this device is accepted: in some cases, the use is forced and thus, does not indicate that the device is really accepted.

This 4-A model is the only one model that considers

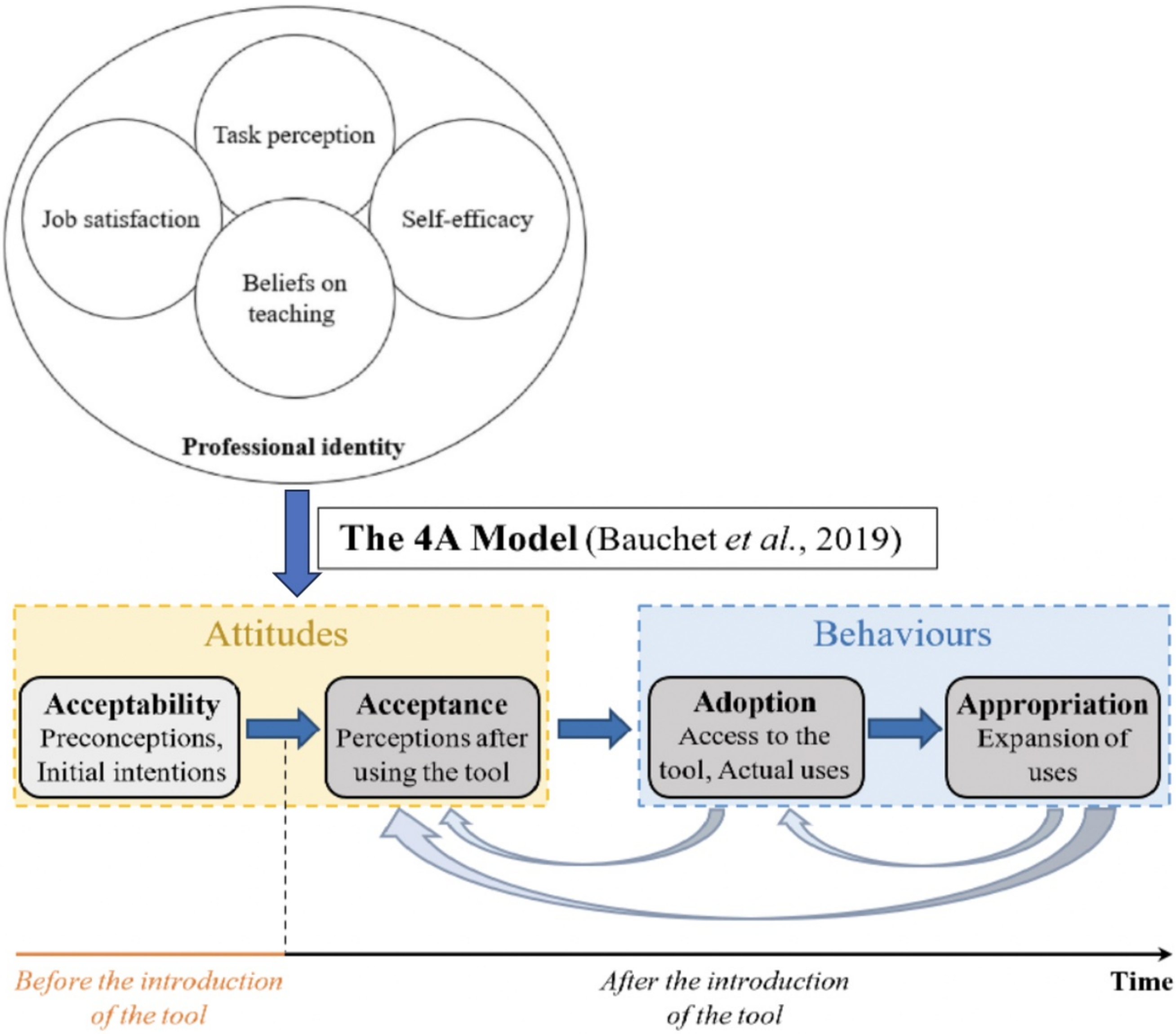

Figure 5. The revised version of the 4-A Model [26] [27]

representations, cognitive biases, as well as the tool's ease of use and adaptability, offering insights into the integration process. This model is also interesting from an ecological point of view by its consideration of professional's perceptions of robots and their interaction with them. The 4-A model highlights that the acceptance of the tool impacts its adoption and incorporation. Hence, professional's view of the robot, its ease of use and the associated usage-related challenges serve as perspective factors for its practical utilization. A progressive handling of the tool allows to facilitate teachers' comprehension and to focus on the use to offer an efficient support, with less workload for professionals.

C. The Integration of Professional Identity into the Revised 4-A model

The revised and the more recent version of the 4-A model integrates the different components of the professional identity to better describe and predict the acceptability of technology, such as robotics systems (Figure 3).

There is consensus in the research that professional identity is a multidimensional concept, but still no unanimous agreement on its central components [56] [57] [55]. However, four main components can be identified that have emerged from a variety of studies as manifestations of professional identity in teacher educators:

- The first of these is task perception, i.e., the individual understanding of the tasks for which a person feels responsible [58][59];

- The second is self-efficacy, the perception of one's ability to deal successfully with the specific requirements of one's profession. Self-efficacy refers to an individual's belief in his or her capacity to execute behaviors necessary to produce specific performance attainments [60][61]. Self-efficacy reflects confidence in the ability to exert control over one's own motivation, behavior, and social environment;
- The third component is the perception of satisfaction (or failure) [62], since experiencing success in a job may lead to a feeling of satisfaction, whereas the experience of failure may result in a feeling of stress;
- The fourth component of professional identity is the personal system of beliefs on teaching and how to put them into practice (in healthcare or in education for instance).

The four elements related to professional identity have strong relationships. For instance, the perception of value that a job brings to workers corresponds to their needs [63][64]: If workers feel that their job meets their needs, they may derive a sense of satisfaction, which may in turn yield benefits, such as good mental and physical health. If, however, workers do not see value in their work, there may be adverse consequences, such as negative emotions and a loss of meaning in work and life. In the same way, self-efficacy, beliefs on education and job satisfaction are strictly interconnected for workers in education [65][66][67] and in health-care domains [68][69]. Because perceived self-efficacy derives from mastery experiences that foster achievements, and achievements, in turn, carry a variety of internal and external rewards, the way that teachers or caregivers perceived self-efficacy is a main determinant of teachers' job satisfaction.

D. Attitudes of the Teachers Towards IA and Robots: Exploratory Interviews

Five exploratory interviews have been conducted with five French teachers working with children with specific needs (i.e., with cognitive impairments) by using AI and robots (NAO or Leka). In their verbalizations, it's easy to detect elements of language that directly concern fears about professional identity:

- Teacher 1: His verbalisations reflect positive attitudes towards AI and robots because they reflect positive impacts on professional identity: "I think there is a lot that AI and robots can contribute. For example, when I used the small robot NAO with my students, I felt like I had an extra teacher in the classroom. And that is really a big benefit for me. I mean, I can't be available to all my students at the same time /.../ when they can ask NAO something /.../ so they're not just waiting for me /.../. That's a big thing for me. But it's true that with AI or a robot alone, without a teacher, it would probably be difficult. But yes, it can be a great help and I am thinking that I will develop new competencies useful for my students";
- Teacher 2: "I'm concerned about this feeling of dependency on technology when you cannot do anything by yourself. That's what I feel is happening, /.../ that we are not real teachers. That worries me more than the surveillance and specifically the surveillance of our children, because it is possible that someone could misuse our data";
- Teacher 3: "What's essential is that teachers grow confident in their ability to think critically and deeply about AI and robots";
- Teacher 4: "When I use a robot, I feel I'm no longer really useful for the children. I feel as if someone is trying to replace me with a machine";
- Teacher 5: "As a teacher, AI and robots can rapidly give me new material to work on, but as an educator proper, I am not really interested because these machines can't replace what I do as a human. And what will the children's parents think? That these machines can do my job?."

These verbalizations confirm that the four aforementioned components of professional identity are important for actions and behaviour in the workplace and may therefore influence the individual's performance, the quality of their actions and their attitudes (e.g., [70]). In other words, these four components of professional identity influence directly attitudes towards technology and then they influence acceptability and thus, the next steps of the process (acceptation, approval, appropriation).

III. Discussion

Robots have become increasingly embedded in the very core of many firms' products, services, and operations, which implies that people's roles and relationships become somewhat inseparable from their interactions with technology and in changing professional roles, which influences one's occupational identity [71] [72] [73] [74]. In particular in the fields of elder care and in the care and education of children and young people, especially those with specific disabling conditions, such as autism, this increasing use of robotics systems and Artificial Intelligence (AI) may be harmful to professions and occupations and some authors have investigated the disruptive potential of robotics [75].

A series of studies revealed three central predictors for AI identity threat in the workplace (changes to work, loss of status position, and AI identity predicting AI identity threats) [48][50]. A recent framework has been created by [48] to better understand and examine "how changes and challenges associated with AI implementation can be understood using this functional-identity framework and some recent framework allows to better understand the future acceptability of AI and robotic systems.

Our theoretical model adds other elements. The real and imagined disruptions of increasingly automated work that will unfold over the coming decades will have profound implications. From the everyday experiences of individual value and worth to the priorities of federal legislation and resource allocation, the reconfiguration of work will have widespread impact. This communication contributes to efforts to shift the ways in which the future of work and the rise of robotics and AI are understood. By proposing a new framework for articulating the resulting disruptions in relation with professional identity, our communication aims to engage with a range of discussions around researches, policy priorities, legal frameworks, and stakeholder decision-making processes. In other words, the crucial questions are: What of the humans who currently provide human-to-human social and educational care? What of their future professional training and identity needs in a world of care and education provision delivered by or, at the very least, augmented by AI and robots?

IV. Conclusion and Future Works

This paper aimed to present the revised and the more recent version of the 4-A model integrating the different components of the professional identity to better describe and predict the acceptability of technology, such as robotics systems. Actually, this revised 4-A model is the only one model that considers representations, cognitive biases, as well as the tool's ease of use and adaptability, offering insights into the integration process. Because the revised 4-A model highlights that the acceptance of the tool impacts its adoption and incorporation, it is also interesting from an ecological point of view by its consideration of professional's perceptions of robots and their interaction with them.

Emerging technology is not an identity threat per-se. Mainly, it depends upon how the professional appraises and evaluates it against the current definition of identity [76] [77]. But technology can be considered as disruptive if it fundamentally displaces an earlier technology, forces organizations to fundamentally change their business model or leads to radical organizational change [78]. Currently, Artificial Intelligence (AI) and robotics systems are considered as two major disruptive technologies in healthcare and education.

Even if the use of robots in workplaces in healthcare or education care can offer multiple advantages, professional role identity can be damaged as AI and robots take the place of people across a broad range of professional tasks. For that reason, professional identity can be managed with specific goals of using robots in work situation and limits of their use had to be explain [79]. As the implementation of robot aims to alleviate mental and physical limits [80], specific tasks must be given to robots, like repetitive or tiresome works, to facilitate the acceptability and to preserve professional identity. In fact, out of place disruption creates negative effects on social perception of the user during a task or, on the willingness to work in collaboration and impacts the HRI [81] [82].

Some surveys reveal that workers and employers tend to be very positive about the impact of AI on worker productivity and working conditions [51]. Around 80% of AI users said that AI had improved their performance at work, compared to 8% who said that AI had worsened it. Across all indicators of working conditions considered (job satisfaction, physical health, mental health, fairness in management), AI users were more than four times as likely to say that AI had improved working conditions as to say that AI had worsened them. This indicates that AI, if used correctly, could contribute to higher productivity and better job quality. But, these previous surveys concern workers and employers in finance and manufacturing. In the domains related to health and education, we can hypothesize that opinions can be very different because these domains are human-centred.

Finally, our framework called Revised 4-A Model is a relevant approach to better understand the following phenomena:

- Workers express some concerns about the impact of AI on job stability and wages;
- AI and robots are already transforming the nature of work;
- The adoption of AI and robotic systems results in significant skill changes, which employers are addressing primarily through training;
- Consultation regarding the adoption of new technologies and a human-centred approach appear to be associated with better outcomes;
- Employers and workers say that lack of skills is currently the greater barrier to AI and robotic adoption.

Note that this research was partially supported by JST-Mirai Program Grant Number JPMJMI22J3 and Mie Prefecture school (Japan) and the Association Jean-Baptiste Thiery in Maxeville (France)

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Construction and Practice of Knowledge Service System: A Case Study of Marine Knowledge

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***Abstract*—In the era of big data, integrating, sharing, mining, and analyzing multi-source heterogeneous massive data to obtain useful knowledge has become an important research content and key issue that urgently needs to be solved in various fields. This paper analyzes and puts forward the marine knowledge and organization and management methods, focuses on the construction and practical results of marine knowledge service platform, and discusses key technical issues such as the integration of marine domain knowledge resources and the construction of knowledge maps. The research results can not only provide personalized and accurate knowledge services for all kinds of users involved in the sea, but also provide reference for the construction of knowledge service system in the ocean and related domain knowledge.**

Keywords-knowledge service; knowledge service system; marine knowledge service; knowledge graph.

I. INTRODUCTION

This paper is based on the previous work originally presented at the Sixteenth International Conference on Advances in DBKDA 2024 [1]. The key technologies of marine knowledge service was added in Section IV.

With the rapid development of Internet, 5G, artificial intelligence, Internet of things and other technologies, as well as the acceleration of digital economy in the world, we are already in the era of "information explosion" or even "post information explosion", and the amount of information in global science and technology, economy, society and other fields is growing at a geometric level. According to the statistics and predictions of the international authoritative agency Statista, the global data volume is about to experience a larger explosion, and the global data generation will reach 2142 ZB by 2035 [2]. With the development of various detection equipment and computing simulation, scientific research has entered the fourth normal form of "data intensive discovery" [3]. Ecosystems, Earth observation, oceans, life and health, astronomical observation and other professional disciplines have generated and accumulated massive scientific data through continuous observation/monitoring [3][4]. The data obtained through continuous, multi-source, and three-dimensional observation and monitoring methods using remote sensing, communication, and other technologies in the fields of Earth observation and ocean observation is growing at a daily terabyte rate [5]. As professional data enters the era of big data, how to analyze and mine a large amount of data to obtain useful knowledge has become an important research content and a key issue that urgently needs to be solved.

The ocean is an important strategic space for coastal countries around the world to strive for their interests and development. With the further development of economic globalization and regional integration, the impact of the ocean on national economic development, political diplomacy, and national security is becoming increasingly significant. With the deepening of the strategy of strengthening the marine power and the Belt and Road Initiative, marine information plays an increasingly important role in supporting national strategic planning and the development of marine undertakings. The demand of the state, the government, high-end research experts, the public, especially engineering and scientific personnel, for marine information sharing and services is growing. Therefore, the construction and application of marine knowledge service system is carried out, Realize the integration and precise services of knowledge resources such as literature data, scientific data, expert institutions, and internet data in the marine field, and provide support services for various users to carry out marine research, marine management, and marine strategic planning.

The rest of this paper is organized as follows. Section Ⅱ presents the related work of this paper. Section III presents the classification and management of marine knowledge resources. Section IV presents the construction and functions of marine knowledge service platform, including knowledge content and organization, platform functionality, and effectiveness. Section V presents the key technologies of marine knowledge service. Section VI summarizes lessons learned, conclusions, and future work.

II. RELATED WORKS

In recent years, professional domain knowledge service has gradually become the development strategy of national science, technology and culture. In September 2015, the State Council issued the "Action Outline for Promoting the Development of Big Data" [6], which clearly proposed to carry out " knowledge service big data applications,

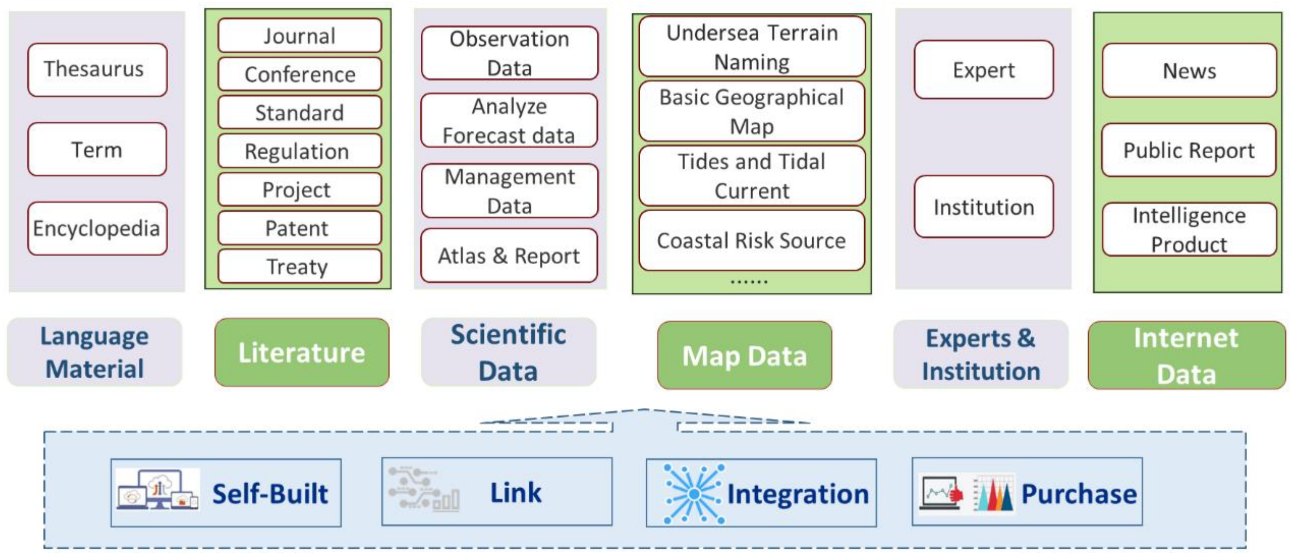

Figure 1. Classification of marine knowledge resources.

establish a national knowledge service platform and knowledge resource service center." In 2016, the construction of the Knowledge Resource Service Center by the China Press and Publication Research Institute was approved to promote the national knowledge resource database engineering project. The Chinese Academy of Engineering launched the construction project of "China Engineering Science and Technology Knowledge Center" in 2012. In 2017, the project was included in the big data project supported by the state. With the overall goal of building a national "engineering science and technology think tank", the project is committed to meeting the needs of the state, the government, high-end researchers, the public, especially engineering and technology personnel, and connecting China's engineering science and technology fields, including agriculture, forestry, meteorology, chemical industry, marine. With the goal of deep knowledge mining, we aim to build various professional knowledge service systems in the field of engineering and technology based on massive data from metallurgy, geographic resources, and other fields. We aim to build a knowledge integration body with the richest engineering and technology information resources, the widest application range, and the strongest practicality in China. Various professional fields have also conducted research and practice in the construction of knowledge systems, the development of knowledge service standards, the processing of knowledge resources, the construction of knowledge service platforms, and the exploration of knowledge service models [7]-[9].

The definition of knowledge is currently not clearly defined. As the most important concept in the field of philosophy, Plato believed that a statement that can be called knowledge must meet three conditions: it must be verified, correct, and believed by people [10]. The term 'knowledge service' originates from the field of enterprise knowledge management. Although current technology and theory connected to knowledge graphs are progressing rapidly, the integration of knowledge graphs with the marine domain is not comprehensive enough to use relevant technology to obtain further information in the marine domain. In fact, large-scale research on knowledge graphs in the marine domain, embracing various facets of oceanography, has only arisen in recent years [11].

This paper focuses on the construction and practice of marine knowledge service system and investigates the key technical problems of marine knowledge resource integration and knowledge map construction. The research results not only provide personalized and precise knowledge services for various marine-related users, but also provide reference for the construction of knowledge service systems in marine and related fields.

III. THE CONTENT AND ORGANIZATION OF MARINE KNOWLEDGE

Knowledge resources are the important basis of marine knowledge service. Determining the classification and management methods of marine knowledge is the foundation for building a marine knowledge service system.

A. *Classification of Marine Knowledge Resources*

Marine knowledge resources mainly include literature data, scientific data, map data, basic corpus data, Internet data, expert institutions and other comprehensive data. The acquisition methods of knowledge resources mainly include self-establishment, purchase, link, integration and so on. The classification of marine knowledge resources is shown in Figure 1. At present, a sustainable and updated marine knowledge resource system covering 85 sub-categories and 6 major categories has been integrated and formed.

Marine literature data mainly covers Chinese and foreign journal papers, academic dissertations, conference papers, sea-related projects, patents, treaties, standards, policies and regulations, etc. in the field of marine science and

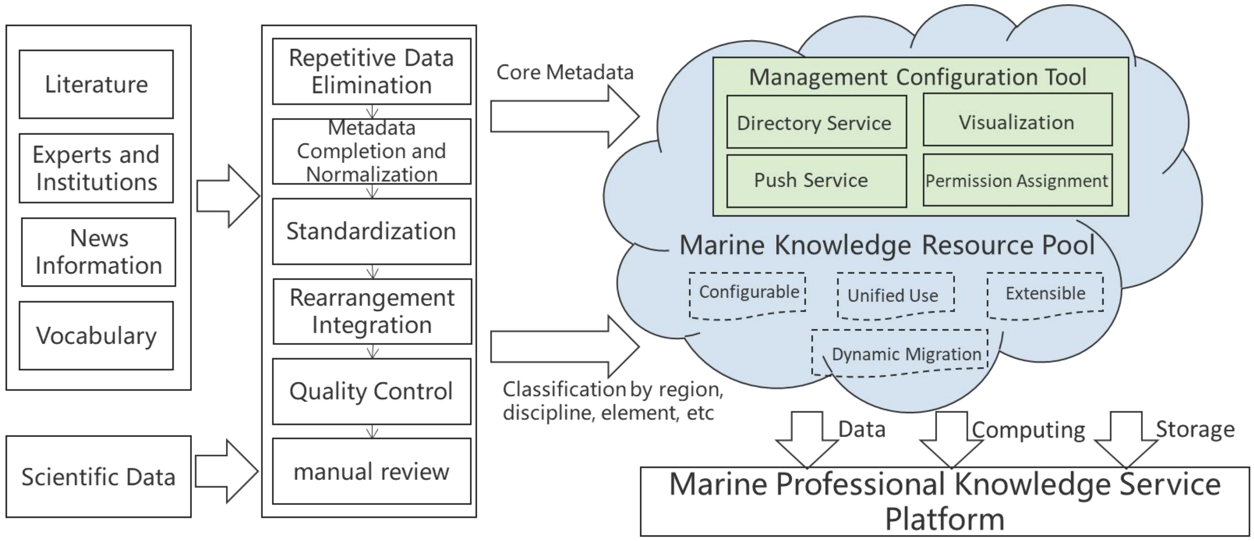

Figure 2. Flow chart of marine knowledge resource management

technology. The data sources are commercial purchase, Ministry of Natural Resources, Ministry of Science and Technology and other ministries and official websites of the government. Basic corpus data includes marine thesaurus, entries and encyclopedias, etc., and the data comes from existing self-built resources in the marine field. Internet data includes news information, public reporting and intelligence products.

Scientific data is the most complex and data intensive part of the marine knowledge resource system. The ocean itself is a huge, complex, and nonlinear system, with extremely complex phenomena and processes, and vastly different spatiotemporal scales [3]. Therefore, marine scientific data is divided into measured data, analysis and prediction products, and comprehensive management data according to their sources and processing methods. Actual measurement data is a standard data obtained through a series of processing, integration, and quality control of ocean data obtained by different observation methods. It is classified into disciplines such as ocean hydrology, ocean meteorology, ocean acoustics, ocean optics, ocean chemistry, ocean biology, seabed sediment, and ocean geophysics. Analysis and forecasting products refer to ocean hydrological and meteorological basic field data and graphic products produced at different time scales, spatial resolutions, and levels. The time scales include calendar year/year, quarter by quarter, month by month, day by day, hour by hour, and even more refined time scales. The spatial resolution includes 1 degree, 1/2 degree, 1/4 degree, 1/8 degree, 1/16 degree, and special customized products in some regions (such as Bohai Bay, Liaodong Bay, etc.). According to different processing methods, products are divided into conventional statistical products, reanalysis products, forecast analysis products, and live analysis products. Comprehensive management data includes marine comprehensive management data such as sea area management, island management, marine economy, forecasting and disaster reduction, and seabed terrain naming, usually in the form of thematic atlases and reports. Map data is to classify, extract and summarize the parts of scientific data with spatial information according to special topics, including basic geographical base map, submarine terrain naming, tidal current stations, coastal risk source and other data. Marine scientific data comes from satellite and ocean stations, buoys, ground wave radar and other field observation stations, as well as daily business management.

B. *Management of Marine Knowledge Resources*

Marine knowledge resource management adopts the principles of “unified construction of resources, on-demand use of services, and automatic update of knowledge”, and uses virtualization technology to build marine knowledge storage resource pools and computing resource pools to realize unified allocation, unified use, extensibility, configuration, and dynamic migration of resources, as shown in Figure 2. Due to the large number of sources of marine knowledge resources, metadata information, data formats and storage methods are quite different. Before entering the knowledge resource pool, standardized description and processing of metadata should be carried out according to certain standards, including repetitive data elimination, metadata completion and standardization, data standardization processing, rearrangement and integration, quality control and manual audit. Among them, the metadata of literature, expert institutions, news information, basic corpus, etc. are standardized in accordance with the metadata specification of China Engineering Science and Technology Knowledge Center [12], and the standardization of marine scientific data is implemented in accordance with the standards and technical specifications of marine information metadata, marine data application record format, and marine observation data management methods. The marine knowledge resource pool provides unified permission management and various resource interfaces to realize catalog service, push service, resource visualization, permission allocation and other functions.

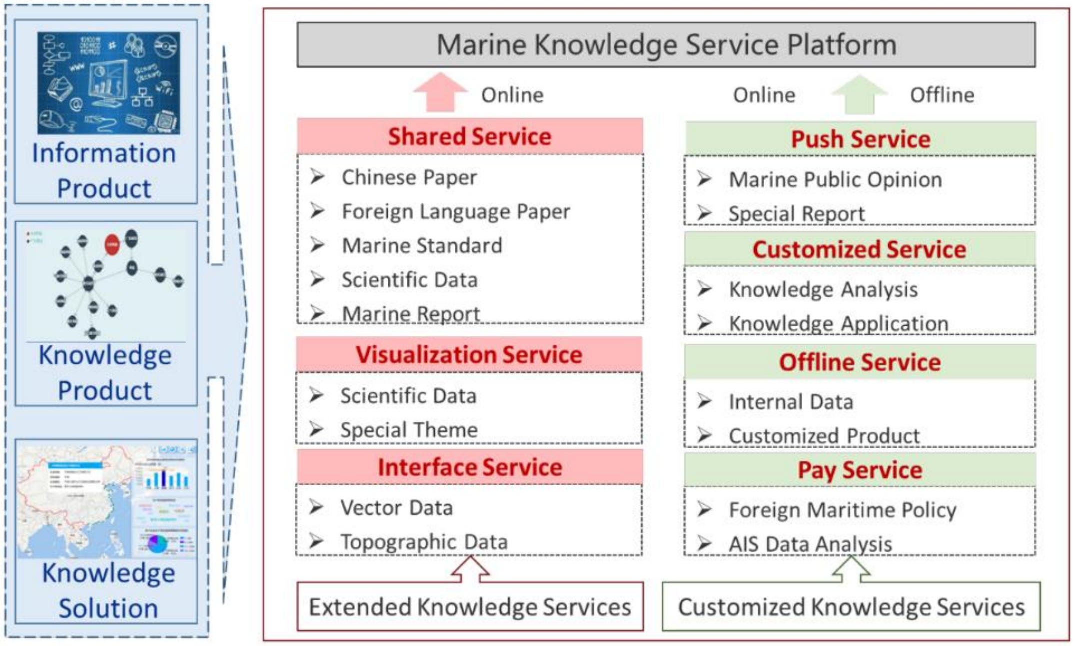

Figure 3. The mode of marine knowledge service, including information, knowledge and solutions

IV. Construction and Functions of Marine Knowledge Service Platform

Knowledge services require specialized and integrated system platform support. The practice of marine domain knowledge service takes the integration and collection of data, processing of information, and analysis and mining of knowledge as the chain to build a resource rich, widely used, advanced and practical marine knowledge system, and realizes the functions of integrated knowledge search, multiple service modes, accurate knowledge application, and comprehensive special topics, providing rich, accurate A three-dimensional knowledge service.

A. One Stop Marine Knowledge Retrieval

Knowledge retrieval is the foundation of knowledge services. Traditional retrieval involves querying based on conditions such as time, space, and subject words. In order for users to quickly find the required data, intelligent retrieval such as full-text and cross language retrieval, as well as building search engines, have become essential functions for many knowledge service platforms or systems. The diversity of marine knowledge resources requires the establishment of a full-text index to achieve a one-stop marine knowledge search. Based on the marine vocabulary (including both Chinese and English), information extraction, filtering, indexing, text classification, word segmentation, and other processing work are carried out on the original corpus. The Solr full-text search engine is used to automatically sort, summarize, and create index files for the processed corpus. Through syntax analysis, internal code conversion Automatic filtering and classification, ultimately achieving classification retrieval, fuzzy retrieval, cross language retrieval, and secondary retrieval, in order to retrieve the knowledge that users need as much as possible. The ultimate goal is to achieve efficient discovery of multi-source heterogeneous marine data resources on the platform, as well as convenient access to original and physical data, providing users with a one-stop intelligent retrieval service of "what you need is where you are, what you see is what you get".

B. Diversified Knowledge Service Methods

The mode of knowledge services is divided into three levels: information services, knowledge products, and knowledge solutions. From the perspective of user needs, it is divided into extended knowledge services and customized knowledge services [13]. Extensive knowledge services are not targeted at specific users or problems, but mainly focus on providing general data and knowledge content in the field, such as ocean knowledge sharing services, visualization services, interface services, etc. Customized knowledge services refer to providing corresponding knowledge content or solutions based on user needs, such as push services, customized services, offline services, and paid services. The ocean knowledge service method is shown in Figure 3.

In extended knowledge services, ocean knowledge sharing services provide data or products to users through search and retrieval, online computing, download and use, etc. For self-built data resources, users are provided with free downloads, paid services, offline applications, etc. For commercial purchases of resources, a small amount of information transmission services is provided in the form of products. Visualization service is to intuitively display scientific data and thematic services through histogram, pie chart, bar chart, facing chart, scatter chart, radar chart,

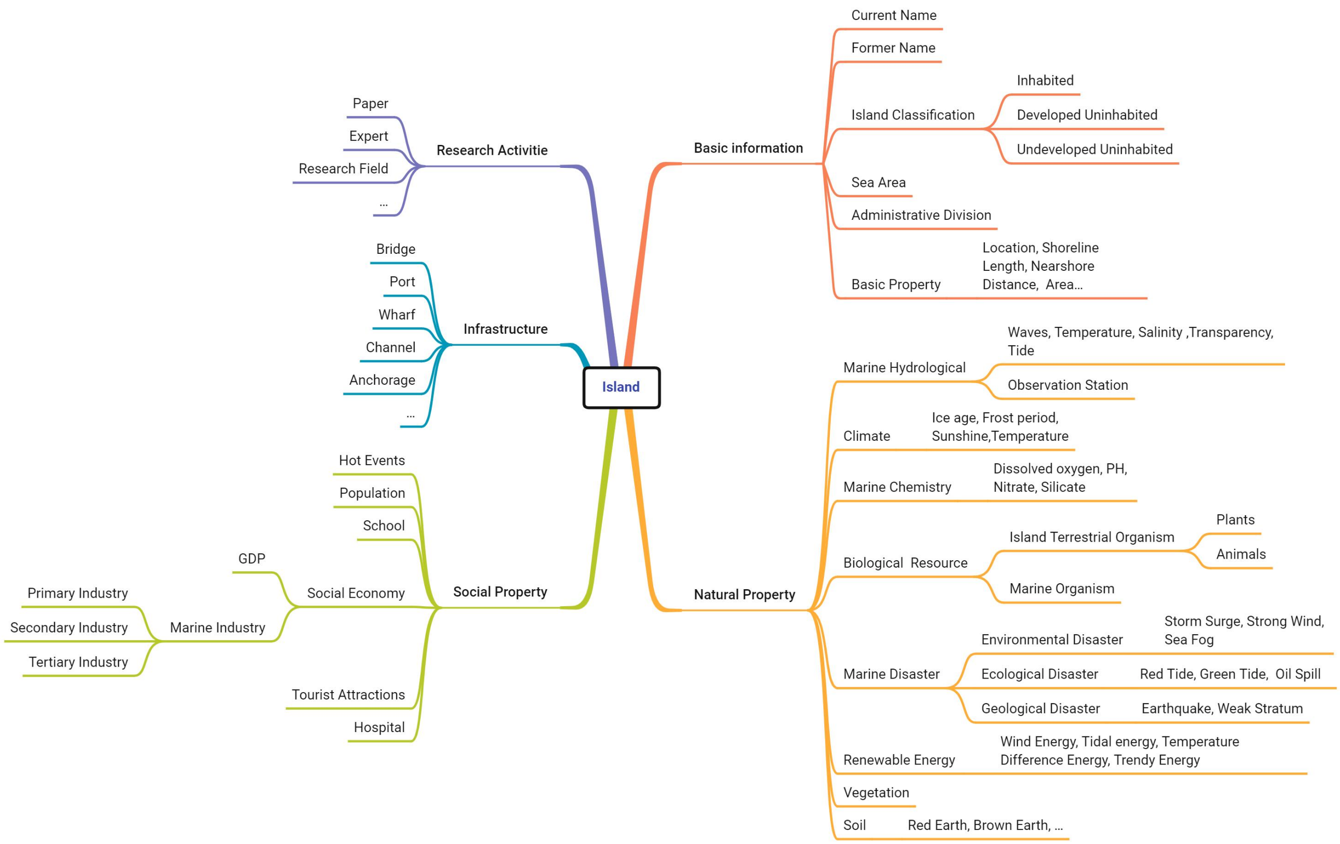

Figure 4. Part of Island knowledge classification system

bubble chart and other chart forms, as well as curve chart, profile map, contour line, contour surface and other two/three-dimensional map display forms, which is conducive to users' intuitive understanding of the characteristics of marine knowledge resources and provides technical support for users' scientific research, marine engineering, etc. Interface services are services that publish vector maps, terrain maps, etc. in the form of interfaces for users to call.

C. Precise Knowledge Application

The marine knowledge service platform focuses on the research fields of national strategy, maritime emergencies, and marine hot spots, studies theme-oriented automatic aggregation technology of knowledge resources, and develops 16 marine thematic knowledge aggregation products such as the 21st century Maritime Silk Road, sea level rise, blue economy, and undersea topography and place names, providing comprehensive, in-depth and accurate thematic knowledge services. Deep processing, indexing and knowledge-based organization of marine data resources are carried out, and knowledge applications such as trend analysis, scholar analysis and institutional analysis are developed. Knowledge maps of typical scenarios such as island development and utilization and site selection for marine ecological restoration are studied and constructed, so as to realize multi-dimensional disclosure and semantic correlation of marine knowledge and effectively support decision-making and application in the field of marine management, as shown in Figure 4.

D. Marine Think Tank Support Services

The platform tracks and compiles important ocean related policies, documents, and reports released by international organizations and institutions in multiple countries and regions around the world, collects, organizes, and analyzes international/regional ocean situations and dynamic information to form international ocean public opinion reports by publishing a series of annual reports such as the China Ocean Economic Statistics Bulletin, the China Ocean Statistics Yearbook, the China Island Statistics Bulletin, and the China Sea Level Bulletin. It also explores areas for tracking and analysis Think tank information service mode combining information reference and data analysis, create a series of marine think tank report products combining "authoritative bulletin, public reports and public opinion analysis", and provide support for major strategic and theoretical research, marine protection and development, global marine governance, marine scientific research and other fields such as marine power, Maritime Silk Road, etc.

E. Results of Construction and Operation

By the end of 2023, a system of sustainable and updated marine knowledge resources covering 85 sub-categories in 6 categories, including scientific data, papers, standards, patent achievements, policies and regulations, and expert institutions in the marine field has been built, totaling about 5 million pieces. It will develop 7 knowledge applications, such as shipping big data analysis and tidal current forecast, and 9 feature topics, such as blue economy and sea level rise, to create an integrated platform for marine information services and knowledge application and provide multi-dimensional and deep marine knowledge mining and analysis services for high-end think tanks, engineers and scientists and the public. The annual user visits are stable at more than 1 million times. Cumulatively, it provides data and report support services for many academicians and dozens of national key research and development programs and local research projects.

V. Key technologies of Marine knowledge service

In the process of constructing the ocean knowledge service system, it is necessary to study the panoramic integration technology of multi-source marine resources and the construction technology of ocean thematic knowledge graph.

A. Panoramic Integration Technology of Multi-source Marine Resources

Marine data comes from a wide range of sources and has various means of acquisition, featuring multi-modal, heterogeneous and multi-scale characteristics. Therefore, it is necessary to study multidimensional data and knowledge fusion technology for specific marine application scenarios, so as to realize in-depth mining of various resources such as marine literature, scientific data and expert institutions, multi-source heterogeneous data fusion, and cross-disciplinary and cross-domain knowledge horizontal association. In order to realize the panoramic integration of multi-source marine resources, this paper carries out data cleaning and conversion of structured data, semi-structured data and unstructured data by making and revising metadata standards, database construction specifications, interface services and other series of standards and specifications, and forms standardized standard data. Then, through the multi-modal data association and fusion, multidimensional data integration, knowledge fusion and other technologies and methods, finally realize the panoramic integration of marine data, laying the foundation for marine data analysis and mining and knowledge services.

B. Construction technology of ocean thematic knowledge graph

There have been attempts in the application of knowledge graph research in the marine field, such as the construction of islands and reefs, and the construction of polar ontologies [14][15]. However, most research focuses on the construction and analysis of knowledge graphs from a bibliometric perspective [16]-[20], and there is a basic gap in the unified knowledge expression mode across multiple marine disciplines and the construction of thematic knowledge graphs to support management and application decision-making. Therefore, in order to build a map of marine domain knowledge, it is necessary to first build a professional knowledge representation model, and then integrate multimodal data such as ocean maps, texts, and numbers, breaking through the automatic construction and reasoning technology of knowledge maps, so as to build a large-scale thematic knowledge map for marine big data analysis and decision-making. In terms of specific technical routes, the construction of professional knowledge representation models usually includes top-down and bottom-up approaches, as well as a combination of the two. The professionalism of the marine field determines the need for expert knowledge participation in model construction, driven by business scenarios, and based on expert knowledge, a combination of top-down and bottom-up approaches is adopted to construct a knowledge model. Then, knowledge extraction technologies such as graph mapping/D2R, wrapper, supervised learning, and knowledge fusion technologies such as entity disambiguation, entity alignment, and knowledge combination [21]-[24] are used to build a knowledge map of multi-source fusion, multi-scale mapping, and multimodal representation. On this basis, we will carry out research on ocean big data decision support technologies such as multi-source information mixed knowledge reasoning [25], complex network analysis [26][27], and graph computing, achieving the updating and improvement of graphs, and ultimately providing intelligent decision support for ocean management applications such as marine ecology and island development and utilization.

VI. Conclusion

This paper analyzes and puts forward the content and organizational management mode of marine knowledge, focuses on the construction and practice of marine knowledge service system from the aspects of knowledge content and organization, platform construction and function, and operation effect, and discusses the key technical issues such as resource integration of marine literature data, scientific data, expert institutions, Internet data, and knowledge map construction. It can provide reference for the development of knowledge services in marine and related fields.

With the advent of the era of big data, it has become a trend in the field of marine data management, mining, analysis and service to quickly discover useful information from numerous data to intelligent and accurate decision-making services. Marine knowledge services are facing huge opportunities and challenges. In the next step, on the basis of continuously promoting the integration and sharing of marine data resources, the construction of marine knowledge service platform will strengthen the development of products for users' personalized needs, take knowledge service as the starting point, promote the transformation of data-information-knowledge-application, promote the realization of industry-university-research-use cooperation demonstration of marine knowledge service, and build the brand of marine knowledge service.

ACKNOWLEDGMENT

This research received founding from China Engineering Science and Technology Knowledge Center Project, grant number CKCEST-2022-1-4. All the data in this research is sourced from National Marine Data Center of China. The authors would like to thank the anonymous reviewers for their insightful comments and substantial help in improving this paper.

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AI-centric Proxy Design Synthesis for Non-Obvious Link/Entity and Higher-Order Network Discernment

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***Abstract*—The discernment of relevant sparse and "Very Small/Non-Obvious" (VSNO) clusters within High Dimensional Data (HDD) and the operationalization of Spatio-Temporal Knowledge Graph Completion (STKGC) for High-Order Network (HON) discernment are NP-Hard. The amalgam of a Lower Ambiguity, Higher Uncertainty (LAHU)/Higher Ambiguity, Lower Uncertainty (HALU) Module (LHM), Isomorphic Paradigm (IsoP) Comparator Similarity Measure Module (ICSM2), Multi-Criteria Decision-Making Module (MCDM2), Information Fusion Module (IFM), AI Energy Consumption Module (AECM), and a bespoke Metaheuristic Algorithm Module (MAM) are delineated in this paper to show the potentiality for the concurrent treatment of VSNO, STKGC, and HON, which are essential for Advanced Analytic Technologies (AAT)/Advanced Anomaly Detection (AAD), At-the-Edge Observational Space Analysis (AOSA), and Continuous Situational Awareness (CSA). These are vital aspects for critical applications, such as, among others, network analysis (e.g., C2 systems) and maritime domain awareness. The described LHM-ICSM2-MCDM2-IFM-AECM-MAM amalgam can be operationalized by a bespoke Graph Convolutional Network (GCN)-Bidirectional Long Short-Term Memory (BiLSTM)-Graph-Attention-Network (GAT) mechanism along with a Robust Convex Relaxation (RCR)-based Deep Convolutional [Neural Network] Generative Adversarial Network (DCGAN)-Hypergraph-Induced Infimal Convolutional Manifold Neural Network (H-IICMNN)-1,2,3,4 architectural construct (GCN-BiLSTM-GAT & RCR-DCGAN-[H-IICMNN]-1,2,3,4 or GBGRDH-1,2,3,4) to address the involved NP-Hard problems.**

Keywords-Intelligent Decision-Making Systems; Artificial Intelligence; Machine Learning; Big Data; Advanced Analytics; Command and Control; Large Scale Complex Networks.

I. INTRODUCTION

The architecting of a discernment capability for Very Small/Non-Obvious" (VSNO) clusters, as well as related links (which might be of a dotted line nature) and nodes (wherein a node might also equate to discerning a Higher Order Network or HON containing other nodes and links), is a considerable feat. Various considerations, such as spatial and temporal, are often presumed; however, in many cases, this information must be appropriately fused (i.e., Information Fusion or IF), as the involved data repositories might be devoid of such temporal and/or spatial information. Data repositories with quadruple representation will likely have temporal information and those with quintuple representation will likely have both spatial and temporal information; however, those with triple representation will often not (without being extended). A determination with regards to IF must be made based upon the involved ambiguity/uncertainty, and such Artificial Intelligence (AI)-centric Intelligent Systems (IS) Decision Engineering Discernment Engines (DE2) (AI-IS-DE2 construct), which illuminate these desired Decision Engineering Pathways (DEPs), are non-trivial to design. As a nice recap, Ding reviews various involved categories: Representation (e.g., Higher-Order Networks or HONs), Prediction (e.g., Spatio-Temporal Knowledge Graph Completion or STKGC for missing links/nodes), Simulation (e.g., ambient Control Signals or CS amidst dynamic topological changes), Inference (e.g., Adaptive Criteria Weighting Systems or ACWS for non-biased/more balanced suppositions), and [Command] & Control (C2) (e.g., elastic/resilient C2) [3]. HON, C2/CS, STKGC, and ACWS have been considered in the aggregate within various works-in-progress and prior works [1][2][3]. After all, by better understanding the involved C2 (which may serve as a HON, thereby having the ability to exercise CS), it will: (1) more readily effectuate IF, (2) better leverage Advanced Analytic Technologies (AAT)/Advanced Anomaly Detection (AAD), and (3) more robustly maintain At-the-Edge Observational Space Analysis (AOSA) as well as "Continuous Situational Awareness" (CSA) for the purposes of DE2. Similarly, ACWS can inform STKGC to affirm the CS, HON, and C2.

For the C2 case, various Global Maritime Domain Awareness (MDA) frameworks have been examined, and it was noted that MDA tend to consist of various constituent Regional Maritime Situational Awareness (RMSA) networks. Typical RMSA architectural constructs generally involve "a Decision Support System (DSS) node" in a lead role and various geographically distributed DSS nodes as part of an "enclaved network" [4]. As the situation evolves, the "enclaved network may evolve," such as into a Multi-Partner Enclave (MPE), or devolve [4]. Depending upon the circumstances, the "interim lead DSS" designation may alternate temporally, as certain DSS nodes may be construed to be more apropos and/or "optimally positioned" to guide/shape the "mosaic-at-large" (e.g., MDA, in this case), such as for IF [4]. The IF criterion may potentially involve ingesting more data, but this will be informed by a particular "Lower Ambiguity, Higher Uncertainty (LAHU)/Higher Ambiguity, Lower Uncertainty (HALU) Module (LHM)" and AI Energy Consumption Module (AECM) [4][5][6].

A. LHM

With regards to the LHM, under a "Compressed Decision Cycles (CDC)" paradigm, which equates to a condition wherein time is of the essence, the LHM will actuate upon "sparse data" or "higher uncertainty…given the condition of lower ambiguity" (i.e., LAHU); this roughly equates to the situation, wherein an Isomorphic Paradigm (IsoP) is recognized, if it has occurred previously "within the historical data" [1][6][7]. In contradistinction, given a state of "higher ambiguity" (i.e., HALU), for which IsoP has not occurred before, the LHM might stipulate the need for "more data 'to lower uncertainty'" [1][5][6]. The LHM will also consider the AEC involved, and this information is provided by the AECM.

B. IsoP Comparator Similarity Measure Module (ICSM2)

The LHM is supported by a bespoke ICSM2, which ascertains the prior occurrence of IsoPs by way of facilitating the derivation of the Optimal Shapley-Nondominated Solution (OSNS) and the Optimal Corresponding (OC) "Generalized Linear 'f'-sided" (GLf) [Spherical] Fuzzy Number (FN) (SFN)" or "(OCGLfSFN)-based membership function" (by way of the Precursor [non-OC] GLfSFN or P-GLfSFN) [7]. These "best-fit approximations" lend to the IsoP determination.

1) Nondominated Solution (NS)

Wu notes that Shapley values (SVs) (various researchers have noted that Monte-Carlo, among other can be leveraged to generate the *f*-th feature along with ML model *m*, feature index *f*, number of iterations *i*, etc.) can be leveraged to transform FN-related Fuzzy Optimization and Decision Making (FODM) problems to "Scalar Optimization Problem[s]" (SOPs) that can be efficiently resolved to segue to the Nondominated Solution (NS), wherein "no one objective function can be improved without" a concurrent degradation to "the other objectives" [7][8]. The OSNS can then be ascertained.

2) OCGLfSFN-based membership function

As noted in the introduction for Section IB, regarding "best-fix approximation," Lakshmana has reported on the efficacy of the "approximations of general non-linear FNs" by way of higher-order linearized Generalized 'f'-gonal FN/SFN forms, "'such as *Tr*iangular, *T*ra*p*ezoidal,' as well as *Pe*ntagonal, *He*x*a*gonal, *He*p*t*agonal, *O*ctago*n*al, etc." [7]; these can be re-expressed as "G*Tr*FN, G*Tp*FN, G*Pe*FN, G*Hx*FN, G*Hp*FN, G*On*FN, etc., respectively" [7]. According to Velu and Ramalingam, "best-fit approximations" can be improved "when higher-order piecewise linear" FNs are utilized to approximate "non-linear information" [7][9]. Along this vein, Augustin asserts that, as one example, G*Hp*FN "can represent more intricate and nuanced degrees of uncertainty" since "certain apropos 'f'-gonal FN/SFN forms" are quite good at "preserving ambiguity" [7][10]. Ban, another advocate of this principle, has a predilection for "*Tr*iangular, *T*ra*p*ezoidal, and semi-*T*ra*p*ezoidal for the 'preserv[ing]…and weight[ing]' of ambiguity" [7][11]. The pathways for deriving the OSNS (a Multi-Objective Decision Making or MODM problem) and the selection of the 'f'-gonal FN/SFN form (a FODM and Multi-Criteria Decision-Making or MCDM problem) are informed by the ICSM2.

C. MCDM Module (MCDM2)

The ICSM2 is a constituent of the MCDM2, which is comprised of Multi-Attribute Decision Making (MADM) and MODM components, each of which has Subjective Method (SM) and Objective Method (OM) constituent elements. By well counterpoising SM with OM, selection bias can be better mitigated, and the MADM/MODM SM/OM (MMSO) amalgam facilitates the operationalization of an ACWS (that informs STKGC, etc.)

D. IF Module (IFM)

For Real World Scenarios (RWS), the MCDM problems, handled by the MCDM2, tend to be nested (e.g., marsupial drones, wherein the main MCDM for the "mother" drone is to deliver the "baby" (a.k.a., "joey") drones to the area of operations, and the joey drones then perform their various tasks, which involve distinct and disparate MCDMs), and IF-related "constituent grey" MCDM problems can be construed to be FODM that are complex "because the measures/objectives tend to" be at odds [7]. Accordingly, the facilitation/derivation of the OSNS (a constituent MODM problem) by the MCDM2's ICSM2 is central, and other contributory, value-added approaches include: (1) the "Dempster-Shafer framework" to address IF "and reasoning under uncertainty," (2) "Zadeh's Type-2 Fuzzy Set (FS) (T2FS)" for IF and tackling "the fused probability with possibility-probability information," as well as (3) "Debois and Prade's FNs" for the encapsulating of "complexity/uncertainty" [7][12][13]. Overall, the overarching intent to preserve ambiguity, uncertainty, et al., via "best-fix approximation" is maintained.

E. AEC Module (AECM)

Of note, LHM actions are shaped by the AEC information provided by the AECM. In essence, there are two counterpoising: (1) the LHM's consideration of the ambiguity/uncertainty counterpoising, and (2) the LHM's consideration of the AEC status — current/anticipated AEC. The latter is a non-trivial consideration, and historically, AEC numbers have been "skewed more towards the training side" [14]. Contemporary times have spotlighted a potential inversion, wherein the AEC for inferencing is oftentimes far greater than that for training [14][15]. This makes sense, for while a single inference "requires much less computation than that" involved in model training, "inference happens far more frequently than model training" [16]. Along this vein, Luccioni notes that "in-depth work quantifying" AEC as well as other inference-related costs "is limited" [16], and Luccioni, Desislavov, and others have asserted that "the total energy cost" for the various segments of the Artificial Intelligence (AI)/Machine Learning (ML) "model life cycle … is very rarely available" and that the AEC "per (one) inference is rarely reported" [16][17]. Ranking industrial organizations concur and posit "that inference loads will increase over time" [18]. For example, AI chip/server provider, NVIDIA, "estimates that 80-90% of the cost of neural networks lies in inference processing," and Castro furthers this by asserting that "training a particular AI model incurs a one-time cost, whereas using an AI model continues to consume energy over time" [19][20]. It then follows that most of AEC "will eventually come from inference" [19][20]. The described lack of AEC data for "the key AI stages (e.g., pre-training, fine-tuning, and inferencing)" likely constitutes a key reason for the potential "dearth of analyses on effective compute (e.g., algorithmic efficiency versus hardware efficiency)" [7]. Even when a certain model has been closely scrutinized, the phenomenon of AEC varying, such as with the involved number of parameters (e.g., "a higher number of parameters" segues to a higher AEC), has not been well studied [7][14][20]. Finally, higher requisite accuracies beget higher AECs, and AAT/AAD necessitates tasks that have an even higher AEC. This facet is oftentimes not well considered in contemporary designs.

F. Metaheuristic Algorithm (MA) Module (MAM)

AEC is heavily impacted by the involved MA, which is operationalized by the MAM. Despite the grim backdrop depicted in Section IE, "there are opportunities to reduce AEC at the MA level," such as "at the convolutional layer," via avenues "that scale well across the AI stages" [7]. By way of contextualizing information, two of the MA bastions are: "Evolutionary Algorithms (EA) and Swarm Intelligence (SI)" [7]. It is recognized that "Holland's Genetic Algorithm (GA) is among the more popular EA" while "Kennedy & Eberhart's Particle Swarm Optimization (PSO) "is among the more popular SI" [7]. Various MA have since "been put forth, but they tend to be derivative variants of EA or SI" [7]. For many cases, the plain vanilla PSO has outperformed the derivatives [7]. This was furthered by a remark, made during a keynote session of the World AI IoT Congress; "oftentimes "purported performance assertions are more marketing than actuality;" in any case, "Nikelshpur and Tappert as well as others have successfully utilized SI, in the form of PSO, for pre-training," "Wang et al. and others have successfully used PSO for fine-tuning," and Babanezhad as well as "others have successfully used PSO for inferencing" [7][21][22][23]. As it is seemingly fit for purpose "'across the AI stages,' PSO-based MA" warrants further investigation" [7].

The aspects discussed within this paper (with utilized acronyms) are presented in Table I (which is drawn from [1]), via five parts: (1) the overarching objectives (e.g., targets, actions), (2) the functional requirements, (3) the constraints (e.g., functional, selection bias, spatial/temporal), (4) certain boundaries, and (5) the requisite components (e.g., constituent elements, which each constitute a separate system). In this way, by Section V (Conclusion & Future Work), it can be evaluated whether the proposed approach suffices in addressing the overarching objectives.

TABLE I. CONSIDERED ASPECTS OF THE LHM-ICSM2-MCDM2-IFM-AECM-MAM AMALGAM (WITH UTILIZED ACRONYMS) [1]

I. Overarching Objectives (e.g., targets, actions) & Case Studies *Decision Support & Decision-Making*
• Intelligent System (IS) • Command & Control (C2) ➢Information Fusion (IF) ↪Multi-Partner Enclave (MPE) ➢Advanced Analytic Technologies (AAT) ↪Advanced Anomaly Detection (AAD) ➢Continuous Situational Awareness (CSA) ➢At-the-Edge Observational Space Analysis (AOSA) • Decision Engineering Discernment Engine (DE2) ➢Decision Support System (DSS) ↪Optimal Decision Engineering Pathway (DEP) amidst ↪Uncompressed Decision Cycles (UDC) ↪Compressed Decision Cycles (CDC) ↪Fuzzy Optimization and Decision Making (FODM) ↪Scalar Optimization Problem (SOP) ↪Nondominated Solution (NS) ↪Optimal Shapley-Nondominated Solution (OSNS) • Multi-Criteria Decision Making (MCDM) with constituent ➢Multi-Attribute Decision Making (MADM) ➢Multi-Objective Decision Making (MODM) ↪Mathematical Programming Methods (MPM) ↪Artificial Intelligence (AI)/Machine Learning (ML) methods ↪Integrated Approaches (IA). ➢MADM/MODM each have: ↪Subjective Methods (SMs) ↪Objective Methods (OMs) Collectively: MADM/MODM SM/OM (MMSO) • Quality Control Program (QCP) ➢Quality Assurance/Quality Control (QA/QC) ↪ Real World Scenario (RWS) case studies ↪Global Maritime Domain Awareness (MDA) ↪Regional Maritime Situational Awareness (RMSA)
II. Functional Requirements *Aspects Needed*
• Knowledge Graph (KG) ➢KG Embedding (KGE) ↪KG Completion (KGC) ↪Spatio-Temporal KG (STKG) Completion (STKGC) ↪KG Reasoning (KGR) ↪STKGR ↪Type-Sensitive (TS) STKGR (TS-STKGR or T2S2KGR) • Discernment Facets: ➢High Dimensional Data (HDD) ↪Sparse Solution Discernment (SSD) ↪Very Small/Non-Obvious (VSNO) ↪*H*DD *V*SNO SS*D* (HVD) ↪HDD-centric Cluster Validity Index (CVI) Measures (HCM)
III. Constraints (e.g., functional, bias, temporal) *Implementation Considerations*
• High Order Network (HON) ➢ HON interactions (HONi) ↪Hypergraphs ↪Complex Manifolds (CMs) ↪Simplicial Complexes (SC) ↪ Homological Percolation Transition (HPT) ➢Control Signals (CS) ↪Control Energy Cost (CEC), ↪Key Control Driver Nodes (KCDN) ↪Influence Dominating Sets (IDS) ↪Positive Influence Dominating Sets (PIDS) ↪Negative Influence Dominating Sets (NIDS), ↪Bak–Tang–Wiesenfeld (BTW)

        ▻Co-Evolution Networks (CEN)
      ▻Elongated Temporal Span (ETS)
      ▻Gramian
        ▻Inverse Gramian
          ▻Vanishing-Moment Recovery Matrix (VMRM)
- Multi-Layer Networks (MLN)

➢Efficient Controllability Problem (ECP)
  ▻*Minimum Controllability Problem (MCP)*
- Relationship Membership Stream (RMS)
  - ➢Probability [& Statistics] Systems Theory (PST)
  - ➢Fuzzy Systems Theory (FST)
    - ▻ Fuzzy Number (FN)
      - ▻ Spherical FN (SFN)
        - ▻Optimal Corresponding (OC) Generalized Linear ‘f’-sided SFN (OCGLfSFN)
          - ▻Generalized (G) ‘f’-gonal FN/SFN forms:
            - ▻G *Tr*iangular FN/SFN (G*Tr*FN/G*Tr*SFN)
            - ▻G *Tr*a*p*ezoidal FN/SFN (G*Tp*FN/G*Tp*FSN)
            - ▻G *Pe*ntagonal FN/SFN (G*Pe*FN/G*Pe*SFN)
            - ▻G *H*e*x*agonal FN/SFN (G*Hx*FN/G*Hx*SFN)
            - ▻G *H*e*p*tagonal FN/SFN (G*Hp*FN/G*Hp*SFN)
            - ▻G *O*ctago*n*al FN/SFN (G*On*FN/G*On*SFN)
    - ▻Fuzzy Set (FS)
      - ▻Intuitionistic FS (IFS)
      - ▻Pythagorean FS (PFS)
      - ▻Neutrosophic FS (NFS), which combines Neutrosophic Set (NS) with FS.
      - ▻Type-2 Fuzzy Set (T2FS), as contrasted to Type-1 Fuzzy Set (T1FS)
      - ▻Spherical Fuzzy Sets (SFS)
        - ▻T-SFS (TSFS)
    - ➢Rough Set (RS)
      - ▻Rough (R)-Fuzzy Set (RFS)
    - ▻Three-Way Soft Clustering (TWSC)
    - ▻Similarity Measures (SimM)
      - ▻Center of Gravity (COG)
      - ▻Radius of Gyration (ROG)
  - ➢Grey Systems Theory (GST)
- AI/ML Implementations
  - ➢ Robust Convex Relaxation (RCR) paradigm
    - ▻Constriction Factor (CF)
    - ▻Particle Swarm Optimization (PSO)
    - ▻Numerical Stability Architectural Construct (NSAC)
    - ▻Number of Function Evaluation (NFE)
  - ➢Sequence of Transformations (SOT)
    - ▻Nonnegative Matrix Factorization (NMF)
    - ▻Gaussian Composite Model (GCM)
    - ▻Multiresolution Matrix Factorization (MMF)
    - ▻Corresponding WT (CORWT)
    - ▻Enhanced CORWT (ECORWT)
    - ▻Wavelet Transform (WT) which include
      -Continuous Wavelet Transform (CWT), whose implementation can include CWT PyWavelet Schema (CPS)
- Explainable AI (XAI)
  - ➢Criteria Weighting Systems (CWS), which might include MMSO, such as:
    - ▻Point Allocation (PA)
    - ▻Analytic Hierarchy Process (AHP)
    - ▻CRiteria Importance through Intercriteria Correlation (CRITIC)
    - ▻Technique of Order Preference by Similarity to an Ideal Solution (TOPSIS)
    - ▻VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)
    - ▻Multi-Objective Optimization by a Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA)

      while other HDD-oriented sub-space approaches include:
    - ▻Clustering in QUEst (CLIQUE)
    - ▻Merging Adaptive Finite Intervals And (MAFIA)
  - ➢Adaptive CWS (ACWS),
- Exemplar Metrics:
  - ➢Performance (P)
  - ➢Consistency (C)
  - ➢Flexibility (F)
- Neural Networks (NN)/Deep NNs (DNNs)
  - ➢Convolutional NN (CNN)
    - ▻Graph Convolutional Network (GCN)
    - ▻Deep Convolutional Generative Adversarial Network (DCGAN)
    - ▻Hypergraph-induced Convolutional Manifold Network (H-CMN)
      - ▻Hypergraph-Induced *Infimal* Convolutional Manifold NN (H-IICMNN)
  - ➢Graph NN (GNN)
    - ▻Graph-Attention-Network (GAT)
  - ➢Recurrent NN (RNN)
    - ▻Bidirectional Long Short-Term Memory (BiLSTM)
  - ➢Model Paradigm
    - ▻Training
    - ▻Fine-Tuning
    - ▻Inferencing
      - ▻Forward Passes (FP)
- Triples, Quadruples, and/or Quintuples (TQQ)

IV. Specific Boundaries

- Cluster Validity Index (CVI), which can be grouped as
  - ➢External Measures (EMs), such as
    - ▻F-Measure (FM)
    - ▻Normalized Mutual Information (NMI)
  - ➢Internal Measures (IMs), such as
    - ▻Calinski-Harabasz (CH)
    - ▻Davies-Boulding (DB)
    - ▻Ball-Hall (BH)
    - ▻Pakhira-Bandyopadhyay-Maulik (PBM)
    - ▻Trace(W) (TW)
    - ▻Point-Biserial (PB)
  - ➢Relative Measures (RMs), which can be construed to be IMs:
    - ▻Dunn-Index (DI)
    - ▻Maulik-Bandyopadhyay (MB)
    - ▻McClain-Rao (MR)

    These can also be grouped as Candidate Lists (CL):
    - ▻Difference-like Criteria (DLC) -> DLC CL (DCL)
    - ▻Optimization-like Criteria (OLC)

V. Requisite Modules (e.g., constituent elements, which each constitute a separate system)

Key Constituents

- ➢LAHU/HALU Module (LHM), which is comprised of
  - ▻Lower Ambiguity, Higher Uncertainty (LAHU)
  - ▻Higher Ambiguity, Lower Uncertainty (HALU) considerations
- ➢Isomorphic Paradigm (IsoP)
  - ▻IsoP Comparator Similarity Measure Module (ICSM2)
    - ▻Isomorphic Heuristical Pathway (IHP)
- ➢MCDM Module (MCDM2)
- ➢IF Module (IFM)
- ➢AI Energy Consumption (AEC) Module (AECM)
  - ▻Units:
    - ▻Joules (J)
    - ▻Watt (W)
    - ▻kilo Watt hours (kWh)
  - ▻Floating Point Operations (FLOPs)
  - ▻[computational] Efficiency (EFF)
- ➢Metaheuristic Algorithm (MA) Module (MAM)
  - ▻Evolutionary Algorithms (EA)
    - ▻Genetic Algorithm (GA)
  - ▻Swarm Intelligence (SI)
    - ▻PSO

Overall, this paper describes an AI-IS-DE2 construct (i.e., LHM-ICSM2-MCDM2-IFM-AECM-MAM) being advanced, whose focus is the discernment of HON so as to better understand the C2/CS at play (and vice versa); in either case, STKGC is leveraged, as is ACWS, by the underpinning Graph Convolutional Network (GCN)-Bidirectional Long Short-Term Memory (BiLSTM)-Graph-Attention-Network (GAT) along with a Robust Convex Relaxation (RCR)-based Deep Convolutional Generative Adversarial Network (DCGAN)-Hypergraph-Induced Infimal Convolutional Manifold Neural Network (H-IICMNN)-1,2,3,4 (GCN-BiLSTM-GAT & RCR-DCGAN-[H-IICMNN]-1,2,3,4 or GBGRDH-1,2,3,4), whose "IsoP scrutinization" of the IsoP repository (i.e., Isomorphic Heuristical Pathway or IHP) to ICSM2 progression is shown in Fig. 1 [7]. The ICSM2 informs the LHM that influences the involved MCDM2, which impacts the IFM.

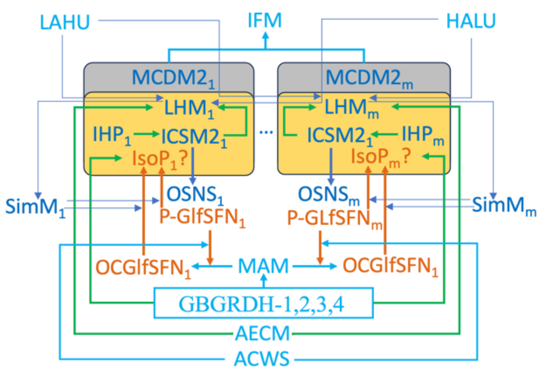


Figure 1. IsoP Scrutinization [7]

Section I provided an overview as to some the overarching objectives of the construct (in addition to some of the tactical objectives, such as IF): AAT (e.g., AAD), AOSA, and CSA for DE2, such as shown in Fig 2. The color schema alludes to the relative AEC in a ROYGBIV fashion.

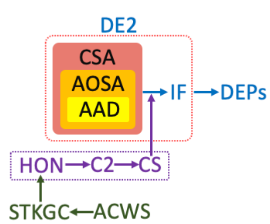


Figure 2. Exemplar Overarching Objectives

It also introduces some key modules: LHM, ICSM2, MCDM2, IFM, AECM and MAM. The paper is, subsequently, structured as follows. Section II provides background information regarding the tasks of: (1) AAT/AAD (a more granular and narrower aperture), (2) AOSA (a wider aperture with greater contextualization), and (3) CSA (an ongoing tasking of AAT/AAD and/or AOSA), and Section III presents key foundational considerations, which include the preferred OCGLfSFN, the ranking of the involved FNs/SFNs (facilitated by the ACWS), the SimM challenge for these FN/SFN, the SimMs and Distance Measures (DMs) for Spherical Fuzzy Sets (SFS) and T-SFS (TSFS), the discernment of clusters/boundaries, the spatio-temporal representation via a quintuple, the use of Type-Sensitive (TS) for RWS, the consideration of Influence Dominating Sets (IDS), ascertaining the Minimum Controllability Problem (MCP), determining the Efficient Controllability Problem (ECP), finding out the Controllability Gramian, establishing the Inverse Gramian, perceiving the phase transitions for High Dimensional Data (HDD) Clustering, and employing various HDD-centric Cluster Validity Index (CVI) Measures (HCM). Section IV provides some preliminary experimental results, and Section V concludes with some observations, puts forth some future work, and the acknowledgements close the paper.

II. Background

A case study, such as MDA, involves IF as well as AAT/AAD, AOSA, and CSA (which comprise the DE2 construct and are all affected by the degree of robustness at the pre-training, fine-tuning, and inferencing phases); these key facets are described below.

A. AAT/AAD

Tasks involving AAT/AAD will necessarily have a high AEC, as the "discernment of relevant sparse and 'Very Small/Non-Obvious' (VSNO) subspace entities within the associated High Dimensional Data (HDD)" will be involved, and more extensive use (and higher AEC) will be involved for AAD-related VSNO [14]. The color schema of Fig. 3 alludes to the relative AEC in a ROYGBIV fashion.

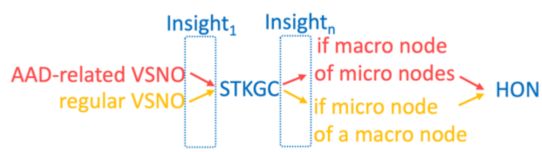


Figure 3. Relative AEC Delineation

B. AOSA

Along the vein of AEC, for AOSO, "optimizing the algorithms" seems to be an approach more in accordance with Hernandez and Brown (of OpenAI) spotlighting the fact that "effective compute" is being driven by "25x growth algorithmic efficiency" as contrasted to "the hardware efficiency gain estimate" of the "8x growth" posited by Moore's Law [14][24]. Desislavov affirms and posits that lower AEC, and improved resultants are likely "attributable to algorithmic improvements" rather than "more computing power" [14][17].

1) Pre-Training:

The import of adequately managing AEC is underscored by Hoffman's research. Hoffmann had found that several contemporary large models "are significantly undertrained," and this leads to situations, wherein "fine-tuning and inferencing AECs" are likely to be "much greater than expected" [14][25]. In fact, "it turns out that the 'convolutional layers'" [a.k.a., Conv] of the Convolutional

Neural Network (CNN) tend to have the 'highest AEC'" (compared to the fully connected layers, and increased filter sizes at the Conv tend to segue to an increased number of parameters, higher computational complexity, and higher AEC), and to address this point, approaches for the reduction of AEC have included "SqueezeNeXt, which builds upon SqueezeNet, or SqueezeNet itself, which utilizes 1x1 convolutions (rather than 3x3), by way of example" [14][26][27]. SqueezeNet is often used in conjunction with a "Fire Module" (i.e., 1x1 convolution filters comprising a "squeeze convolution layer" and an "expand layer" consisting of 1x1 as well as 3x3 convolution filters) [14][26][27]. A "Fire Module" or "Fire Layer" is referred to as FL, and when a series of FLs is used, it can be referred to as SFL. A Modified Squeezed DCGAN You Only Look Once (YOLO) version 3 (v3) Implementation (MSYv3I) can incorporate these notions, as shown in Figure 4. In addition, alternative transformations (distinct and disparate from the Conv or more energy-efficient convolutions with alternative numerical methods) can be leveraged.

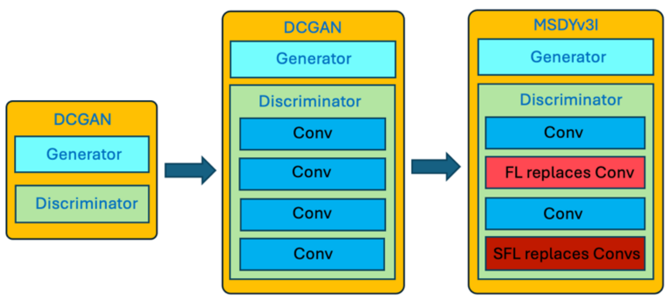


Figure 4. MSYv3I of FL and SFL

2) Fine-Tuning:

Fine-tuning can be construed to be "additional training of the pre-trained model on a more task-specific subset of the original dataset," which substantially changes the pre-trained model, such as via an ACWS, "so as to better conform with the dataset and/or task-at-hand" [14]. In addition, "Wang, Knack, and others note that with regards to AEC, there is a 'need to study fine-tuning…separately from' pre-training 'and inference workloads'," for while pre-training AEC costs can be relatively steady, fine-tuning and inferencing AEC costs can "vary greatly," as they are dependent upon the task-at-hand, the desired accuracy, and the robustness of the pre-training [14][28][29]. This is especially the case when the deployed model is undertrained (as contrasted to being overtrained "past the Chinchilla optimal") [14].

3) Inferencing:

Moving from fine-tuning to inferencing, it is generally recognized that the works of "Li et al. as well as Canziani et al. are among the first robust examinations regarding inference costs" [14][17], and several interesting observations are put forth; for example, Canziani notes that it has become current "practice to run several trained instances of a given model over multiple similar instances" [14][30]. This "practice is known as model averaging," usually involves an ensemble of Deep Neural Networks (DNNs), and "dramatically increases the amount of computation required at inference time to achieve" the specified accuracy (or, given the involved ambiguity/uncertainty, the degree of quantitative exactitude) [14][30]. Clark puts it quite well by noting that the involved AI first needs to "'understand…the query then 'thinks' of an answer," which "thereby increas[es] the involved AEC" [14][31]; this is consistent with a statement made at a keynote session of the World AI IoT Congress: "it's not just about detecting but understanding." For this ensemble paradigm, the "AEC is multiplied accordingly" segueing to a much higher multiple for the aggregate AEC [7].

C. CSA

Taking the proxy case of MDA, the likelihood/probability of a large model size, high accuracy requirements for the involved AAT/AAD, and a high number of Forward Passes (FP) is quite elevated [14]. Also, as "MDA is typically associated with mission-critical activities," it has been noted that "the involved fine-tuning" will "likely be extensive and ongoing" [14]. Moreover, CSA will "necessarily involve higher-order AEC tasks" (e.g., AAD) that will necessitate high FPs [14][16]. As MDA "and other similar mission-critical" RWS "are likely prioritizing quality of results," the various involved modules are likely to be calibrated accordingly [14].

With regards to the overall involved AEC, researchers have noted that "Desislavov's estimates tend to be quite close to reported measured values," so "the Desislavov approach is adopted," for this paper, "wherein inference Floating Point Operations (FLOPs) are focused upon and 'the efficiency metric FLOPS per Watt' (Watt=W) is re-expressed as 'FLOPS per Joule' (Joule=J), so as to express the [computational] Efficiency (EFF) and AEC, such as in (1):

EFF in units: FLOPS/W=[FLOPs/s]/[J/s]=FLOPS/J (1)

AEC=FP/EFF in units: [FLOPs]/[FLOPs/J]=J)" [14][17].

Inference AEC is task-dependent, and as one simple example, the task of "object detection" (e.g., in an AAT case) has "a higher AEC than image classification," and aberrant object detection (e.g., in an AAD case) has an even higher AEC [14][16]. Experimentation by Lucioni had found that inference AEC tended to be much higher than expected, and "the 'mean and standard deviation of inference energy' in kiloWatt hours (kWh) 'per 1,000 queries' was 542% and 2000% greater, respectively" [14][16][17]. Lucioni further found that the "utilization of 'multi-purpose models for discriminative tasks' had a higher AEC when 'compared to task-specific models for these same tasks'," and the differential was quite high: "2-3x to 5-7x" [14][16][17]. Furthermore, any requisite "increase in accuracy," such as throughout the course of AOSA and/or CSA, can segue to "a dramatic" "increase in the required FLOPs for" FP [14][17].

III. Theoretical foundations & considerations

A. Preferred OCGLfSFN

Continuing from Section I, a goal of the involved MA (for which the MAM is responsible) is to ascertain the OCGLfSFN. Prior to segueing to this OC form, there is a precursor non-OC form (i.e., P-GLfSFN), as previously delineated in Fig 1. For example, Augustin acknowledged the predilection for G*Hp*FN for its ability to "represent more intricate and nuanced degrees of uncertainty" while Ban favored G*Tr*FN, G*Tp*FN, and semi-G*Tp*FN for the preservation of ambiguity and weighted ambiguity [7][32][33]. Whatever the preferred form, the choice of the precursor Generalized 'f'-gonal FN/SFN form (e.g., P-GLfSFN) affects the efficacy of the utilized "defuzzification method" (i.e., "the transformation of a FN/SFN into a crisp form") [7]. The significance of this centers upon the intricacy that "as the LHM contends with the counterpoising of" ambiguity/uncertainty, the precursor non-OC form, which best preserves ambiguity, is likely to be optimal for facilitating/deriving the OCGLfSFN.

B. The Ranking of FNs/SFNs

There are numerous "ranking methods for the discussed pre-cursor [non-OC form] Generalized "'f'-gonal FN/SFN form (e.g., P-GLfSFN), and the appropriate selection" is central [7]. For example, Velu and Ramalingam noted that "a ranking method which works very well for" G *He*x*a*gonal FNs/SFNs "may have some shortfalls when it is extended for" G *O*ctago*n*al FNs/SFNs [7][8]. Similarly, "a ranking method which works very well for" G *O*ctago*n*al FNs/SFNs might have "some shortfalls when it is used for" *Tr*iangular or *T*ra*p*ezoidal FNs/SFNs [7][34]. In any case, the ranking mechanism (facilitated by the ACWS) informs the precursor non-OC to final OC form.

C. The Similarity Measure (SimM) Challenge for FN/SFN

With regards to the ranking methods referred to in Section IIIB, the underpinning measures typically involve various SimMs. Gogoi & Chutia noted that while there are a myriad of methods (each with advantages/drawbacks), "a universally accepted 'silver bullet'" SimM "for ascertaining the similarity between" FNs/SFNs "does not necessarily exist" [7][35]. They also noted that a "'literature survey reveals that most of the' SimM 'are being developed based upon'" the following parameters: "geometric distances, height, area, perimeter, 'Center of Gravity (COG),' 'Radius of Gyration (ROG),' etc." [7][35]. It was noted in [35] that for various studies, with the exception "of Hejazi et al. (2011)," certain "glass ceiling" SimM methods (e.g., "failing to 'give reasonable similarity between pairs' of FNs when one FN 'is identical for both the pairs'") "are being carried forward" into contemporary works [7][35]. This is reminiscent of our prior finding that certain bugs/issues in various frameworks/libraries/toolkits, such as made available via assorted developer platforms, were being carried forward into various projects/papers. To aggravate matters, "FNs are simply a special case of a" FS, and "beyond FS, there" are other FS variations; these include the Atanassov Intuitionistic Fuzzy Set (IFS), Pythagorean Fuzzy Set (PFS), and Neutrosophic Fuzzy Set (NFS) [7][36][37]. The IFS, which is often leveraged for "coalition decision-making," is comprised of constituent elements that "have both membership function u and nonmembership function v, such that $u + v <= 1$, and hesitation margin h, such that $u + v + h = 1$" [7]. Other situations are better addressed by PFS, "wherein $u + v >= 1$ (or $u + v <= 1$) and $u^2 + v^2 + h^2 = 1$" [7][36]. Yet other cases are better handled by NFS, which combines "FS with NS" [7][37]; delving into this, Das notes that while FS addresses "uncertainty" by the utilization of "membership grade," Smarandache's NS tackles "uncertainty using truth, indeterminacy, and falsity member grades" [7][37]. Furthermore, Ashraf, Gundogdu & Kahraman, Mahmood, etc. have "contributed to the notion of…SFS, which 'is the generalized structure over' the referenced FS (e.g., IFS, PFS, and NFS)" [7][38].

D. SimMs and Distance Measures (DMs) for SFS/T-SFS

Various SimM approaches have been adapted for the SFS ecosystem, as noted by Zhang, and Wei observes, by way of example, that a plethora of "SimMs for SFS 'based on the cosine and cotangent function' have been" put forth [7][39]. Likewise, certain combinatorials, such as "Jaccard, Exponential, Square root cosine for SFS," etc., have been employed as pragmatic implementations of SimMs [7][40]. With regards to DMs, "Donyatalab and others have examined 'Minkowski, Minkowski-Hausdorff, Weighted Minkowski and Weighted Minkowski-Hausdorff distances for SFSs'" [7]. Overall, there have been numerous SimM and DM advances, and among these, researchers, such as Wu, have "focused on the T-SFS," which is a "'specific case of NS'" (a.k.a., "n-hyper SFS") [7][39][40]. According to Wu, T-SFS is quite adept in contending with "uncertainty information" and "can handle information that SFSs…cannot process" [7][40]. Accordingly, the SimMs/DMs of T-SFS show promise for higher efficacy.

E. Discernment of Clusters/Boundaries

Despite the prospective high promise, the use of SimMs and DMs for clustering should also have concomitant methods of *Boundary* Detection (BD) for enhanced efficacy. As a case in point, regardless of the type of Knowledge Graph (KG) involved, they are often incomplete. Along this vein, researchers have criticized "Static KG (SKG) for neglecting temporal information" [41][42]. Others have critiqued Temporal KG (TKG) for neglecting spatial information [41][43]. Accordingly Spatio-Temporal KG (STKG) seems promising, and Ye notes that for the associated "KG Completion (KGC)," such as that of STKG Completion (STKGC), "discriminative methods (a.k.a., conditional methods that discern *boundaries* among labels, classes, etc.) endeavor to, by way of example, 'predict the possible label' (e.g., node name, line segment name, etc.)" [44]. Wei further clarifies this by noting that "discriminative methods focus on discerning elements of the" involved Triples, Quadruples, and/or Quintuples (TQQ) to "'efficiently construct large-scale' KGs, 'which often require'" "an ensemble," "multiple models" "and/or cascading succession of models" [41]. According to Zeb, the objective is to "undertake KGC" (e.g., STKGC) to "determine the 'unobserved" and/or complete the observed TQQ, thereby facilitating sufficient/efficient inference" [45]. Along this vein, "robust KGC can, potentially, facilitate reducing the inference load and the associated AEC" [41].

F. Spatio-Temporal Representation with a Quintuple

With regards to the referenced STKGC, "Nayyeri suggests that 'spatio-temporal facts can be represented as a quintuple' (s/h, p/r, o/t, l, τ), 'where l reflects the location information (spatial)'" rather than simply using the triple or quadruple representation [43]. "Nayyeri further notes that the 'quintuple representation in the form' (?, p/r, o/t, l, τ),(s/h, ?, o/t, l, τ), (s/h, p/r, ?, l, τ), (s/h, p/r, o/t, ?, τ) or (s/h, p/r, o/t, l, ?) 'is especially suitable because for each incomplete quintuple, four of the five elements are always present'" [43]. In support of Nayyeri's assertion, "Dihedron algebra" is known to be 'a rich 4D algebra of hypercomplex spaces' that can operationalize geometric operations in higher dimensions" [43].

G. Type-Sensitive (TS) for RWS

The TQQ issue (e.g., the extraction potential, or lack thereof, of the triples, quadruples, and quintuples of the TQQ amalgam) is further explored, and "according to Zhang, many of the 'current models have difficulty distinguishing representations of the same entity or relation at different timestamps'" [46]. He refers to this phenomenon as an "entity type information gap" [2]. As a very simplistic example, the relation 'invent,' 'devise'," modify, hybridize, etc., "could connect head entities of type 'AI company'," tech startup company, ML firm, etc. "to tail entities of type 'AI algorithm'," ML algorithm, AI/ML technique, ML method, etc. [2]. Pertaining to "cases such as this, He [et al.] points out that this apriori knowledge" regarding "entity type information" and/or "relation" connectors can provide insights into the likely and apropos "entity type information" for the unknown tail entity. After all, "its position in the vector space should not be far away" [47]. This paradigm constitutes the essence of being "Type-Sensitive" (TS)," and a correlation is made by He et al. that for RWS, "an entity tends to belong to multiple types'" [2][47]. Accordingly, the TS approach, such as TS-STKGC, "might better lend towards RWS" [2].

H. The Consideration of Influence Dominating Sets (IDS)

As noted in Sections III E through G, boundary, spatio-temporal, and TS distinctions help to clarify the sets at play; this is vital for the consideration of IDS, which are typically divided into two groupings: Positive Influence Dominating Sets (PIDS) and Negative Influence Dominating Sets (NIDS). Both PIDs and NIDs must be taken into consideration for the overarching IDS, which is often contextualized by "the Bak–Tang–Wiesenfeld (BTW) sandpile effect of non-equilibrium systems" [41]. Particularly in the case of "Multi-Layer Networks" (MLN)," which pervades RWS, "Grilli had found that HON-related IDS" "interactions have a stabilizing influence within LSCN, and the existence of HON nicely explains many RWS" [41][48][49]. While understanding HON-related IDS, it is useful to undertake the resolving of certain problems to progressively contextualize the state of and/or the prospective controllability. In the course of understanding HON-related IDS, it is useful to undertake the resolving of certain problems to progressively contextualize the state of and/or the prospective controllability. Of note, this involves the progression from the resolving of the Minimum Dominating Set Problem (MDSP) (which centers upon "determining the smallest dominating set of a given graph") to that of the Minimum Controllability Problem (MCP) (which centers upon ascertaining a pragmatic dominating set — that might not necessarily be the smallest — for a given graph).

I. Minimum Controllability Problem (MCP)

First, with regards to MCP, Nguyen articulates the distinction that MDSP is "more suited for a static" Large Scale Complex Network (LSCN), and in contrast, Terasaki points out that solving the MCP is "more suited for dynamic LSCN" [41][50]. Lin adds to this by discussing the notions of a connection condition, which is referred to as a "Critical Connection Component" (CCC) and represents "an *infimal* strongly connected component" as well as rank condition; the rank equates to the number of singular values and the condition is the ratio of *max:min* singular values [41][51][52]. According to Lin, the involved/studied "system is structurally controllable if and only if [iff] a connection condition…and a rank condition…are both satisfied" [41][51][52]. However, as noted by Alizadeh, an approach that "ensures controllability" that is "equivalent to solving a combined maximum matching" (for which Berge's Lemma might put it best—maximum matching is achieved if and only if [iff] there is no augmenting path) is a different matter entirely [41][53].

J. Efficient Controllability Problem (ECP)

Second, progressing from MCP to ECP, Gokler notes that ECP might be the more practical problem to contend with [41][54]. According to Lindmark, the ECP "contends with minimizing the number of requisite CS" and "the requisite Control Energy Cost (CEC)" [41][55]. CS and CEC should be considered in tandem, for "Chen asserts that 'if the number of" CS 'is small, the' CEC 'demanded…could be prohibitively high'" per CS [41][56]. In contrast, "the CEC 'is reduced exponentially as the number of' input CS increases" [41][56]. An extraordinarily elevated CEC would not be practical to achieve, and "controllability for only a limited temporal span" or window may not meet the mark for the envisioned sustained C2 [41][56]. For all intents and purposes, "practical controllability has the criteria of persistence over an Elongated Temporal Span (ETS) so as to be able to effectuate actual/effective control when needed/desired" [41][56]. As noted by Gao, "the optimality problems at hand" "could be construed to center upon" "an optimal number of CS (CS_{opt})" functioning as IDS "on an optimal number of Key Control Driver Nodes (KCDN) ($KCDN_{opt}$)" at a reasonable/sustainable "optimal CEC (CEC_{opt}) over an ETS_{opt}" for effective/efficient control of a LSCN [41][57]. To effectively discern CS, KCDN, CEC, and ETS, the various MLNs and involved HONs should be posited. This discernment pathway leverages: (1) the informative nature of Co-Evolution Networks (CEN), and (2) the insights provided by complex manifolds" [41][56].

1) Informative Nature of CEN

First, information derived from adjacent networks or those at other levels (e.g., MLN) "can be quite informative" from a CEN perspective, particularly if network enlargements/enhancements were made to support the other involved network(s). Likewise, if an outage of one network affected another, certain other suppositions can be made [41]. RWS include KGC facilitation "by, say, knowledge of" adjacent network(s) (e.g., communications network) "interoperating"/co-evolving "alongside an involved" LSCN (e.g., "power grid"). Other examples of intertwined networks (which might be mutually reinforcing and/or opposing) include that of a milk kinship network and tribal political network (i.e., CENs) [41]. Oftentimes, "knowledge of the involved networks across various jurisdictional/functional demarcation boundaries" can be invaluable for STKGC [41].

2) Informative Nature of Complex Manifolds (CM)

Second, researchers, such as Battiston, have examined both "the informative nature of CENs" and "the stabilizing influence of HON" [58]. Battiston, Vazquez, and Sun & Biaconi note that "HON topologies can be" expressed by hypergraphs, even more "complex hypergraphs ('hypergraphs of hypergraphs' or chygraphs)," and "multiplex hypergraphs ('a set of hypergraphs…with the same set of vertices')," respectively [41][58][59][60][61][62]. Extending this point, Ding suggests a more "robust characterization" of "HON topologies" can be effectuated by an amalgam of CMs [41][63]. The CM is described by Voisin as having "'complex-valued coordinates (called holomorphic coordinates)' assigned to positions on a manifold" [41][64]. As noted in [41], "CMs can provide invaluable insights, and 'a physical system embedded on a twisted topological complex manifold' can bring out 'fundamental physical properties of an unknown system,' such as 'if and when' a 'system is undergoing a *phase transition*'" [41][65]. When CMs are considered against the "BTW principle and set against the described LSCN controllability/uncontrollability optimality problems," such as CEC_{opt}, "the impact of existing HON topologies" becomes much clearer [41][63][64].

K. Controllability Gramian

Prior to arriving at CEC_{opt}, it is often useful, certainly for quality assurance/quality control purposes, to obtain "the minimum CEC (CEC_{min}), which Klickstein asserts, "can be characterized by the controllability Gramian" [41][66]. For the discussed case, wherein C2 can be achieved, the "Gramian matrix should be well-behaved" [41][67]. In other words, the "sensitivity to perturbation" (i.e., "the condition number") and the CEC is not prohibitively large [41][67]. In contrast, when the Gramian matrix is ill-conditioned, C2 is not able to be effectuated, and the condition number is indeed prohibitively large [41]. In essence, "for the latter case, the LSCN is not able to arrive at the 'final state in the prespecified time within a predefined precision'" [41][67]. Lindmark notes that the handling of the "Gramian matrix is paramount, as some strategies involve 'comput[ing] in closed form...when the time of the transfer tends to infinity' and physical controllability will not manifest" [41][55]. As noted by Zhou, this "accentuates the case for CS augmentation and/or accelerant approaches" to enhance the probability of actual C2 'as contrasted to theoretical, mathematical controllability'" [41][67][68]. The expectations for more robust and accurate controllability are particularly high for the case of dense/homogeneous LSCN (vice sparse/heterogeneous LSCN) with similar sub-LSCN [41][68]. Along the same vein of moving to quintuples to, potentially, operationalize the spatio-temporal aspect, "Zhang noted that temporal LSCN, which exhibit link temporality" — something akin to "'attaching a virtual driver node to that link'— tend to be more physically controllable" [41][69]. The sequitur thought is that spatio-temporal LCNS will likewise, ostensibly, be more physically controllable. Taking these collectively, in essence, from the vantage point of CS, "if one set of Key Control Driver Nodes (KCDNs) "can influence another set of KCDNs" so as to not only influence the involved LSCN, "but also peer LSCN," higher/lower-order LSCN, and/or HON "to a particular interim state, it then follows that the ultimate desired state is more likely to be attained" [41].

L. Inverse Gramian

Continuing the point of CS, according to Ludice, the likelihood of success for CS_{opt} (e.g., "CS base candidate set and/or CS augmentation set") is intricately tied to the "diffusiveness/permeability of the LSCN," which "constitutes a potential indicator of the susceptibility for LSCN controllability" [41][70]. As another indicator, when the susceptibility for LSCN controllability is high, the inverse Gramian exists [41]; when the susceptibility for LSCN controllability is low, the inverse Gramian does not exist [41]. On this latter note, "a corresponding Vanishing-Moment Recovery Matrix (VMRM) is a suitable approximation of the inverse Gramian," as it "guarantees n vanishing moments of wavelet tight framelets" [41][71]. Abebe further notes that "as the number of vanishing moments increases, the polynomial degree of the wavelet also increases," so there are lockstep characteristics [41][72]. Grochnig asserts that "the potential advantage of this is that" "'wavelet tight frames can,' therefore, 'be derived from any multiresolution analysis'" [41][73]; "this segue[s] to the discerning of" the collective phenomena regarding the LSCN, and two other aspects are also important in this regard: (1) Percolation, and (2) Giant Component.

1) Percolation of a LSCN

Sun defines Percolation as positing "the fraction of nodes in the Giant Component' of a LSCN" [41][61]. In essence, Percolation is evidenced when the average node degree >1 and is indicative of the manifestation of the "Giant Component."

2) Giant Component of a LSCN

Sun notes that a "Giant Component" is a CCC that encompasses a substantive portion of the involved graph's vertices, and a "non-zero Giant Component" is required for the discerning of "'collective phenomena…emerging from' diffusiveness/permeability, etc." [41][61].

M. Phase Transitions for HDD Clustering Discernment

The IDS traits and stabilizing effect of HON underpin many RWS phenomena. These HON are comprised of "'both hypergraphs and Simplicial Complexes' (SC)" [41][61]. Zhang asserts that HON interactions (HONi) "'shape collective dynamics differently in hypergraphs and' SC" and points out that HONi "'increase[s] degree heterogeneity in' SC" while HONi 'decrease[s] degree heterogeneity in [random] hypergraphs'" [41][74]. Of significance, "the amalgam 'insights provided by these two constituent elements of HON are not dissimilar to the insights gleaned via the paradigm of CEN.'" [41]. Lee focuses upon SC and notes that it "has been 'shown to reveal a rich *phase [transition]* diagram' for 'link percolation'" (e.g., the impairing of network connectedness via the deactivating of the involved link/node) [41][61][75]. Insights into the "likeness in structure" (i.e., homological) and into the activation/de-activation of nodes/links temporally (i.e., percolation) is indicative of the involved HON topology. Accordingly, Lee notes that the Homological Percolation Transition (HPT) is also insightful since it denotes the emergence of a burgeoning cluster as the number of SCs increases [41][61][75]. Lee also notes that the CM expression for the hypergraph can also be insightful, and it can be combined with the "the value-added proposition of the SC and hypergraph interplay (in a 'CEN'-like fashion)" for revealing the HON phenomena [41][61].

N. HDD-centric Cluster Validity Index (CVI) Measures (HCM)

Axiomatically, robust HDD clustering is central to VSNO ascertainment. In turn, CVI are vital measures in assessing the resultant "optimal" number of clusters. The CVI measures suitable for HDD (i.e., HDD CVI Measures or HCM) are categorized into: "External Measures (EMs), Internal Measures (IMs), and Relative Measures (RMs)" [1]. EMs have the value-added proposition of capitalizing upon "cluster structures/resultants from data sources not necessarily intrinsic to the clusters and data at-hand" [1]. IMs have the advantage of capitalizing upon the affinity aspect (e.g., cohesion/compactness) that "exists predominantly within the clusters and data at-hand" [1]. Researchers, such as Vendramin posit that "RM can be construed to be a subset of IM" [1][76] [77][105][106].

IV. Experimental Results and Discussion

Section IIIA described how a key goal of the involved MA is the derivation of the OCGLfSFN, and this process is, in turn, heavily dependent upon the precursor non-OC Generalized "'f'-gonal FN/SFN form(s) selected (e.g., P-GLfSFN). This choice is very much informed by the ranking method leveraged (informed by the involved MODM, such as OSNS), as discussed in Section IIIB. Underlying the ranking method are the validity measures utilized, and this typically involves SimMs, such as for SFS ("'the generalized structure' over' 'IFS, PFS, and NFS'") [7][38]; this aspect is described in Section IIIC. Section IIID furthers this by noting that SimMs are used in conjunction with DMs for both SFS and the more robust T-SFS extension. Accordingly, experimentation involving SimMs/DMs for SFS/T-SFS seems apropos, and this is reviewed in Section IVA.

Likewise, Section IIIE notes that the SimMs/DMs should necessarily be accompanied by *boundary* detection (e.g., among classes, etc.), such as via STKGC discriminative methods. Section IIIF notes that the quintuple representation can well capture spatio-temporal information that the quadruple (i.e., temporal information only) and triple (i.e., no temporal information) are unable to; hence, the quintuple representation is well suited for STKGC. Section IIIG then discusses the "entity type information gap" and introduces the notion of TS. While Sections IIIE/F/G helped to clarify the sets at play (via boundary, spatio-temporal, and TS distinctions), Section IIIH notes the consideration of IDS, via PIDS and NIDS. Section III I/J reviews the various considerations, such as IDS (for the MCP and ECP), and articulates the notion of CEC. Section IIIK notes that prior to determining CEC_{opt}, the ascertainment of the precursor CEC_{min} can be useful, and it is well reflected by the controllability Gramian. Section IIIL notes that if the involved LSCN is indeed controllable, the inverse Gramian will exist; along this vein, the VMRM is an accepted approximation of the inverse Gramian, and this sets the stage for the architectural construct to be utilized. It is also noted that as the prospective controllability LSCN becomes clearer, the Percolation and Giant Component lend toward that understanding. Section M notes that the SC and hypergraph interplay also well contribute to that understanding. While the multiplex hypergraph is quite revealing regarding the collective phenomena, SC is quite revealing with regards to *phase transitions*, and the HPT (which provides further *transition insights*) is particularly informative. Overall, the use of *phase transitions* for HDD clustering discernment is articulated. Section IIIN delineates HCM and notes that it is a critical facet for gauging HDD clustering, which is at the core of VSNO determination. Accordingly, experimentation involving the choice of HCM seems fitting, and this is reviewed in Section IVB.

Finally, the architectural construct is reviewed in Section IVC. There were two principal reasons for certain experimental testbed architectural modifications: (1) the consideration of DCNN performance degradation amidst large intra-class variations, and (2) the necessity of shifting to a GBGRDH-1,2,3,4 construct so as to leverage the "more task-specific H-IICMNN *infimal* convolution mechanisms to serve as 'efficient solvers'" for the 1,2,3,4 functional roles [41][116]. Central to the overarching architectural construct was the LHM, as it impacted the use of the involved Non-Operational Data (NOD), Situational Awareness Data (SAD), and Operational Data (OD). The baseline NOD data contextualizes the OD [5]. Likewise, SAD also contextualizes the OD "in an ongoing fashion," such that when sufficient OD enriches the IHP repository, the LHM may decide that it is not necessary "to actuate upon" further OD under CDC conditions [5]. When OD is contextualized "by SAD as well as NOD," it lends to the IHP [5]. The IHP, in turn, is underpinned by an Inherent Uncertainty Construct (IUC). The items of this paragraph are all discussed in Section IVC with an accompanying Fig. 7.

A. Experimentation with SimMs/DMs and SFS/T-SFS

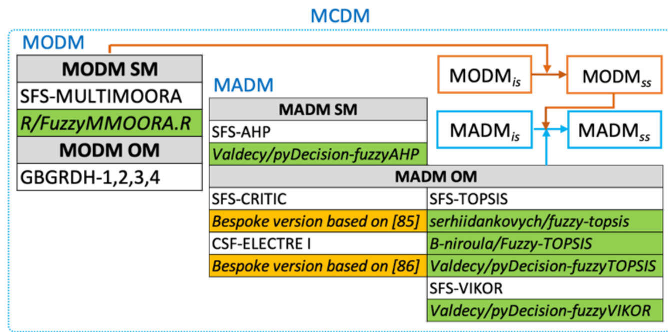
Preliminary experimental forays involved an examination of certain SimMs and DMs discussed in this paper and within the literature [78]. Table II depicts some of the affirmed resultants, and with regards to the color coding, "green denotes comparable performance, and orange signifies that the comparison was inconclusive" [7]. The entries include experimentation by Gundogdu & Kahraman as well as Sharaf, who collectively leveraged "Hwang & Yoon's Technique of Order Preference by Similarity to an Ideal Solution (TOPSIS) and Opricovic's VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods" [7][79].

TABLE II. EXEMPLAR AFFIRMED SIMM AND DM RESULTANTS [7]

		1	2	3	4	5
1	SFS-TOPSIS (Gundogdu and Kahraman)					
2	SFS-VIKOR (Gondogdu and Kahraman)					
3	SFS-TOPSIS (Sharaf)					
4	SFS-VIKOR (Sharaf)					

Then, TOPSIS and VIKOR as well as other MMSO methods were organized into their relevant categories. For example, "with regards to MADM SM, Ortega et al. proposed using SFS with Saaty's Analytic Hierarchy Process (AHP)" [7][80]. For MADM OM, apart from TOPSIS and VIKOR, Kahraman's use of "SFS with Diakoulaki et al.'s CRiteria Importance through Intercriteria Correlation (CRITIC) method" is presented along with Akram's use of "Roy et al.'s ÉLimination Et Choix Traduisant la REalité (ELECTRE) method as pertains to Complex SFS (CSF)" [7]; "the extended method is referred to as CSF-ELECTRE I" [7][81]. For MODM SM, Gundogdu's use of "SFS with Brauers & Zavadskas' Multi-Objective Optimization by a Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA)" is listed [7][82]. For MODM OM, Hanine put forth that "Mathematical Programming Methods (MPM), ML, as well as Integrated Approaches (IA)" should be incorporated into the considered approach [7][83][84]. Along this vein, as the utilized GBGRDH-1,2,3,4 architectural construct "qualifies as such (e.g., MPM/ML/IA), it was utilized for the MCDM OM" [7]. As noted in [83], the construct was devised such that the "MODM solution set ($MODM_{ss}$) facilitates the MADM input set ($MADM_{is}$) to $MADM_{ss}$ progression" [83]. In the spirit of open-source experimentation and leveraging open-architecture and various open-source pathways, various packages (e.g., frameworks/libraries/toolkits) from "Github and other repositories were experimented with" [7], and a sampling of the various MMSO packages/sortings are shown in Table III.

TABLE III. EXEMPLAR MMSO IMPLEMENTATIONS [1][7]



As indicated in [7], it was non-trivial "to appropriately adapt FNs to SFNs and SFSs," and for "several cases, modifications of the involved method had to be" scrutinized against the ongoing work delineated in the literature. Among other exemplars, the "modification of CRITIC to a fuzzy paradigm was based upon, among others, Pamucar's work" [7][85]; "modification of ELECTRE I to a fuzzy paradigm was predicated upon, among others, Sevkli's work" [7][86]. For other instances, various "conversion guides" (e.g., "Amidi & Amidi R-Python") and "online converters" (e.g., "CodeConvert's Online R to Python Converter") were utilized, such as for the "FuzzyMMoora function" (e.g., "R/FuzzyMMOORA.R") [7]. Then, for the ensuing examination, three key metrics were utilized: (1) Performance (P) ("which is highly dependent upon the" Numerical Stability Architectural Construct or NSAC), (2) Consistency (C) (a useful indicator for both NSAC and the Number of Function Evaluation (NFE) (an indicator of the convergence rate — "e.g., a small NFE depicts a faster convergence rate"), and (3) Flexibility (which can be indicative of the potential for "adaptation, hybridization, etc.") [7]. Certain "comparative evaluations" were conducted, and some "interim findings are reflected in" Table IV [7].

TABLE IV. EXEMPLAR MMSO BENCHMARKING [7]

	P	C	F
SFS-AHP			

	P	C	F
SFS-CRITIC			
SFS-TOPSIS			
SFS-VIKOR			
CSF-ELECTRE I			

	P	C	F
SFS-MULTIMOORA			
GBGRDH-1,2,3,4			

For Table IV, the color coding (is as follows. Red denotes worse performance while the darker shade of green denotes better performance; the progression of colors follows the ROYGBIV sequence and indicates the gradations of performance. With regards to the interpretation of Table IV, "for the conditions set within this paper, as delineated in Table IV above, it seems that SFS-MULTIMOORA and the" GBGRDH-1,2,3,4 (which supplanted the prior construct) "warrant further investigation" [7]. "For those cases, wherein the MMSO conjoined multiple packages, the various pairings were designed to be well counterpoised" by way of "complementary structures (e.g., PA is matrixed while AHP is hierarchical) and/or roles (e.g., criteria weights can be derived by CRITIC and, subsequently, ranked by TOPSIS)" [7]. The value-added proposition of an ACWS has long been put forward by researchers, and a well-counterpoised MMSO construct operationalizing an ACWS, which might buttress STKGC (a weight-aware task) is invaluable.

B. Experimentation with Selecting Apropos HCMs

Laborde, Vitelli, and others have asserted that Sparse Solution Discernment (SSD) has not been sufficiently "explored prior to the writing of this paper" and that SSD, such as that pertaining to VSNO "subspace clusters" in HDD, remains in a "fairly nascent state" [1][87][88]. With regards to VSNO clusters in HDD (i.e., *H*DD *V*SNO SS*D* or HVD), SSD is NP-Hard. This should be of no surprise since, throughout the years, researchers have articulated ("and the literature is rife with examples") the "sensitivity of prototypical clustering classifiers" "to the placement of the initial seeds, noise, and the lackluster efficacy when confronted by varying cluster sizes, densities, shape[s], etc." [89][90][91]. The robustness of the HVD is based upon the buttressing "workflow sequences, the involved measures," and "the efficacy by which similitude is gauged" [1]. Along this vein, Wang, Govaert, Nadif, etc. posited that "insight could be gleaned from the relationships among the subspace elements, such as that of submatrices (e.g., homogeneous subsets of data)" [1][91]. Taking a different approach, Majdara, Li, Xianting, etc. "proposed density-based approaches" [1][92]. Different still, Zhao, Du, Lu, etc. "put forth grid-based approaches," and "still others have introduced hybridized approaches [1][92][93]. For example, Agrawal et al. introduced a density-based and grid-based approach referred to as Clustering in QUEst (CLIQUE)," and "as a follow-on enhancement to CLIQUE," Nagesh et al. introduced "Merging Adaptive Finite Intervals And (MAFIA)" [1][93][94]. Yet "other approaches include those that are Wavelet Transform (WT)-based," and this should be of no surprise, since WT are a recognized method "to summarize high-dimensional data in a few numbers" [1][83].

The HVD mechanism is also "underpinned with soft clustering," ("this is contrasted to 'hard clustering, wherein there is classification into only one cluster'"), and "this provides the requisite versatility of more granular and variegated classification" [1]. This "characterization of soft versus hard clustering should be reminiscent of" Type-2 Fuzzy Set (T2FS), as opposed to Type-1 Fuzzy Set (T1FS), "which only accommodates membership invariableness" [1]. With regards to the soft clustering, "Three-Way Soft Clustering (TWSC) 'nicely suffices for the [HVD] purposes at hand,'" as it has the nuance of having "samples in the positive region as belonging to the cluster, samples in the boundary region as partially belonging to the cluster, and samples in the negative region as not belonging to the cluster" [1][96].

Moving from HVD to HCM, Tavakkol et al. have noted, "to the best of our knowledge, there is not any" HCM "in the literature that is designed for uncertain objects and can be used for validating the performance of uncertain clustering algorithms" [1][104]. To set the stage for the HCM exploration, Section IIIN noted that "RM can be construed to be a subset of IM, which can be construed to encompass 'Optimization-like Criteria' (OLC) and 'Difference-like Criteria' (DLC), and 'RM can refer, in particular, to DLC, wherein a baseline reference can be established and utilized to determine relative improvement(s) over a certain time frame'" [1][105][106].

Along this vein, previously, Milligan and Cooper had undertaken an examination "the IM/RM of 'McClain-Rao' (MR) as an OLC," but in a potential difference of findings, "Vendramin et al., among others, found that MR 'performed significantly better (eight times more accurately)' when transforming DLC to OLC (e.g., better results) prior to any evaluation" [1][106]. Along this vein, an exploration was initiated to determine "which HCMs have been considered for facilitating the DLC Candidate List (DCL)" [1]. The premise is that "if the classification related to DLCs can be augmented, and the involved transformations, such as that of DLC to OLC, can be accelerated," then HVD can be enhanced [1]. "The need for a robust HCM apparatus is underscored by Tavakkol, Vendramin, and others," and some of the findings are reflected in Table V [1].

TABLE V. HCM EXPERIMENTATION FACETS FOR DLC TO OLC CANDIDACY [1][5]

I	II	III	IV	V	VI	VII	VIII	IX
MR	DLC	Min;Elbow	WB	$O(nN^2)$	✓	✓	✓	
BH	DLC	Max_{diff};Elbow	W	$O(nN)$				
DI	OLC	Max	WB	$O(nN^2)$		✓	✓	
PBM	OLC	Max	WBD	$O(n(k^2+N))$				✓
TW	DLC	Max_{diff} ;Elbow	W	$O(nN)$				
PB	OLC	Max	WB	$O(nN^2)$				✓

Regarding Table V, Column I lists certain HCMs: MR, Ball-Hall (BH)," Dunn Index (DI), "Pakhira-Bandyopadhyay-Maulik (PBM), Trace(W) (TW), and Point-Biserial (PB)" [1]. Then, Column II lists "the DLC/OLC presort, as presented by Vendramin and Liu" [1][106][107]. Column III indicates the leveraged method to determine optimality, via "Min" ("the smallest index value") and "Max" ("the largest index value") [1][108]; regarding "Max," "Max_{diff} refers to the optimal K segueing to the maximum difference 'between…successive slopes'" [1][63][107][108][109]. Column III also notes various "inflection points;" these inflections are denoted by "elbows" (e.g., positive concavity) and "knees" (e.g., negative concavity), as applicable. Then, Column IV indicates "Within-cluster (W), Between-cluster (B), and full Dataset (D)," in accordance with "Powell's convention/nomenclature," and Column V provides the "computational complexity" [1][109][110][106][111]. Those columns with relatively strong performance "for the various normal distributions, increasing degree of overlap, global optimum, as well as paradigms that are generally affirmed (and/or are affirmed by other benchmarks) are checked off for the pertinent cells of Columns VI, VII, VIII, and IX, respectively, and commonalities are green highlighted" [1].

C. *Experimental Testbed Architectural Modifications*

As noted in Section IV, the VMRM had set the stage for the architectural construct to be utilized. Section IVB had also noted that HVD approaches included density-based, grid-based, and WT-based. As Continuous WT (CWTs) "are particularly amenable to time series analysis," can well handle "wavelet tight frames with *n* vanishing moments," and have "successive convolutional layers (which contain the cascading of ever smaller 'CWT-like' convolutional filters)," "CWTs are the preferred WT embodiment" for the experimentation within this paper [1][41][71][83]. It is also readily operationalized aboard the GBGRDH-1,2,3,4.

Other considerations included the fact that the very nature of HVD involves VSNO and "large intra-class variations," and "Jin noted that when a prototypical Deep Convolutional Neural Network (DCNN) is confronted with 'large intra-class variations, the performance of the traditional [D]CNN models degenerates dramatically'" [41][112]. Thus, *as one principal reason*, the prior instantiation was modified to that of a GBGRDH-1,2,3,4 was to take the DCNN performance degradation aspect (amidst large intra-class variations) into consideration. This rationale will be addressed in segments. Also, given the C2/CS impetus and the notions of HON as well as MCP/ECP, it was more pragmatic to supplant the prior DCNN approach "with the more task-specific H-IICMNN *infimal* convolution mechanisms to serve as 'efficient solvers,' as noted by Lambert" [41][116]. Thus, *as a second principal reason*, the original instantiation was modified to that of a GBGRDH-1,2,3,4, wherein the H-IICMNN-1 would now fulfill the role "as the key solver for the involved RCR optimization problems," H-IICMNN-2 would now fulfill the role "as the key solver for the non-convex problems inadvertently spawned by the RCR," H-IICMNN-3 would now fulfill the role "as the key solver for certain modified involved functions," H-IICMNN-4 would now fulfill the role "as a numerical stability stabilizer for the construct," "and a DCGAN" would now fulfill the role "as a mitigator against mode failure" [41]. This paradigm is shown in Fig. 5 below. Hence, the RCR-DCGAN-[H-IICMNN]-1,2,3,4 aspect has been addressed.

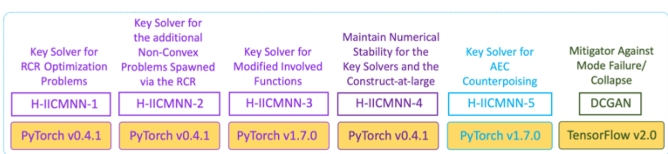


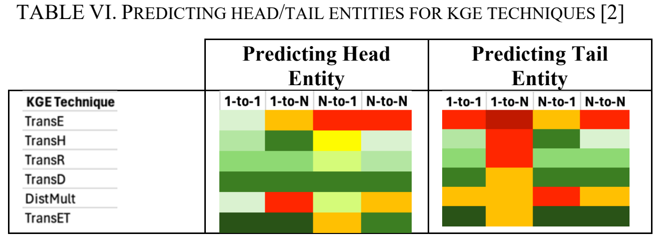
Figure 5. GBGRDH-1,2,3,4 Construct with H-IICMNN functional roles [1][14]

With regards to Fig. 5, H-IICMNN-1 was tasked with ensuring high Quality of Service (QoS) for the involved RCR optimization problems, which require consistent numerical stability. For this reason, PyTorch v0.4.1 was chosen. H-IICMNN-2 was tasked with handling additional non-convex problems that were inadvertently spawned via H-IICMNN-1. H-IICMNN-3 was tasked with handling various modified functions that have been previously shown to produce errant results due to signature and dependency issues. PyTorch v1.7.0 was deemed to be acceptable in this regard. However, H-IICMNN-4 was tasked with internal training for the GBGRDH-1,2,3,4 construct's overall stability, thereby mitigating against known numerical instability issues arising from the use of PyTorch v1.7.0; hence PyTorch v0.4.1 was utilized for H-IICMNN-4. As a TensorFlow v2.0 DCGAN implementation has been shown to exhibit consistent stability, it served in a complementary fashion (as an additional generator) so as to assist in mitigating against "mode failure" (a.k.a. "mode failure/collapse" or the "Helvetica Scenario"), which occurs when adversarial NNs, that are undergoing contemporaneous training, experience an aberrant convergence or simply fail to converge [2][1].

With regards to the GCN-BiLSTM-GAT, researchers have affirmed the various facets of the amalgam. For example, "Zhang affirmed the 'expressive power' of GCN" [118]. "Siami-Namini affirmed the use of the BiLSTM for its 'better predictions,' such as 'in longer prediction horizons' over 'regular LSTM-based models'" [2][119][120]. Hou had found that Graph-Attention-Networks (GATs) well serve as "neighborhood aggregators to learn the entity and relational features of the central entity neighborhoods" [2][121]. "Hamilton affirmed the use of the GAT for its computational efficiency" [122]. "Hou furthers this by noting that the BiLSTM-GAT amalgam can 'capture the interaction features between multi-relational facts and…temporal information' along with a relation-specific weighting schema (as an encoder-decoder structure)" [2][121].

Along the vein of Explainable AI (XAI), a contribution of the bespoke task-specific H-IICMNN was to enhance discernment via a more balanced operationalization since, in the case of RWS, "the Gaussian assumption usually does not hold" [41][123]. In contrast to the [moderate-tailed] Gaussian distribution, the long-tail distribution tends to be prevalent "in KGs", and "strongly unbalanced data with a long-tail is ubiquitous in numerous domains and problems" [41][124][125][126]. Moreover, "learning with unbalanced data causes models to favor head classes," and this is indeed the case for the long tail in RWS [41][125][126]. Hence, the utilized STKG Embedding (STKGE), to achieve the STKGC, needs to be well balanced across both classes (i.e., head and tail), and Table VI demonstrates a possible layered approach.

TABLE VI. PREDICTING HEAD/TAIL ENTITIES FOR KGE TECHNIQUES [2]



For Table VI, the color coding (like that of Table IV) is as follows. Red denotes worse performance while the darker shade of green denotes better performance; the progression of colors follows the ROYGBIV sequence and indicates the gradations of performance. In it of itself, Table VI only sets the stage, for there are more Complex Relationships (CR) that "extend beyond 1-to-N, N-to-1, and N-to-N," such as 1-1-N, N-1-1, 1-M-1, N-1-N, N-M-1, 1-M-N, and N-M-N [2]. Lin points out, such as in the case of one exemplar dataset, "there are 485,661 triples of 1-1-N, 520,476 triples of N-1-1, 211,457 triples of 1-M-1, and 26,943 triples of N-1-N, and the number of head entities with 1-M-N…is 10,143" [2][127]. Therefore, the Table VI relationships of 1-to-1, 1-to-N, N-to-1, and N-to-N must be re-examined in the context of the CRs "to better discern the varied 'relations between a pair of entities'" [2][127]. In addition, "as noted by Cai, 'generating discriminative negative samples is essential since failing to do so may hardly improve the model or even cause gradient vanishing' (wherein the associated gradient may become so small and tend toward the point of 'vanishing,' which then obviates any weighting schema to effectuate updates)" [2][42][129].

Ultimately, certain promising techniques were extended, via He et al.'s framework, the "Type-augmented Knowledge [Graph] Embedding (TaKE)," which "can be combined with any traditional KGE models" "under no explicit type [of] information supervision" and can facilitate "both type constraint and type diversity with low time and space complexity" [2][41][128]. Leveraging this approach, the STKG Embedding (STKGE) "with a Type-Sensitive (TS) extension" becomes TS-STKGE (a.k.a., T2S2KGE). With T2S2KGE as the "generic form," wherein the involved "KGE is replaced with the extended model," T2S2-DistMult and T2S2-ComplEx ("wherein ComplEx is an extrapolation of DistMult") are formulated [2][41][129][130]. In a similar fashion, "T2S2-HyTE (an extension of HyTE, which is an extension of TransH) was inferior to that of T2S2-Hybrid-TE (wherein Hybrid-TE is a hybridization of TransD and HyTE)" [41][129][130]. Ultimately, T2S2-ComplEx and T2S2-Hybrid-TE were utilized for the T2S2KGE, and the performance is noted in Table VII [41][130].

TABLE VII. HEAD/TAIL PERFORMANCE FOR T2S2KGE TECHNIQUES [41]

	Predicting Head Entity				Predicting Tail Entity			
T2S2KGE Technique	1-to-1	1-to-N	N-to-1	N-to-N	1-to-1	1-to-N	N-to-1	N-to-N
T2S2-ComplEx								
T2S2-Hybrid-TE								

For Table VII, the color coding (like that of Tables IV and VI) is as follows. Orange denotes worse performance while the darker shade of green denotes better performance; the progression of colors follows the ROYGBIV sequence and indicates the gradations of performance of the listed STKGE Techniques against various types of KG relationships (e.g., 1-to-1, 1-to-N, N-to-1, and N-to-N) [41].

The application of the pertinent KGE technique and the ensuing KGC that is construed to be a part of the IUC rubric for informing "the HVD, which further informs the IHP" is part of the ongoing Validation/Dynamic Fine-Tuning (VDFT) process employed [5]. As noted in [5], central to the described workflow is the utilization of "Zadeh's Fuzzy Systems Theory" with regards to "T2FS (a.k.a., IUC-1a)" and "'Rough-Fuzzy Set' (RFS) '(a.k.a., IUC-2a)'," "which is an extension of IUC-1a and "Pawlak's Rough Set (a.k.a., IUC-1b)" [5]. Significantly, "IUC-2a can well accommodate the notion of an affiliation, 'but not necessarily absolute inclusion'" [5][130]. In furtherance of this, "Deng's Grey Systems Theory (a.k.a., IUC-2b) can enhance the precision of IUC-2a" [5]. With regards to utilization, IUC-2b can be utilized, "if the relationship/membership (e.g., entity, attribute, etc.) is discontinuous" [5].

On the contrary, if the relationship/membership is continuous, "then other Probability [& statistics] Systems Theory approaches might be utilized, such as Information Entropy Methods (a.k.a., IUC-3), whose strength resides in ascertaining 'unknown attribute weights'" [7][131]. Simply put, "whether the relationship/membership is discontinuous or continuous (e.g., pulsed, rather than continuous), it can still be construed as a Relationship/Membership Stream (RMS)" [5]; the RMS, in the context of MCDM (e.g., MADM/MODM), is shown in Fig. 2. In addition, the "Dempster-Shafer framework" can be useful for considering multiple membership functions, and "Debois and Prade" extend this to "family of membership functions" [132][133].

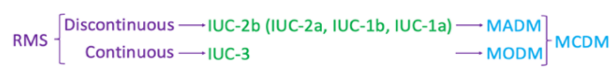


Figure 6. RMS Paradigms for the IUC [5]

Overall, the utilization of Zadeh's T2FS, Gundogdu's "rendition of SFS" ("which is quite useful for multi-dimensions"), and Yao's approach collectively segue to TWSC, which is one of the constituent elements of T2FS-SFS-TWSC (TST) amalgam [5]. This is contextualized within Fig. 7.

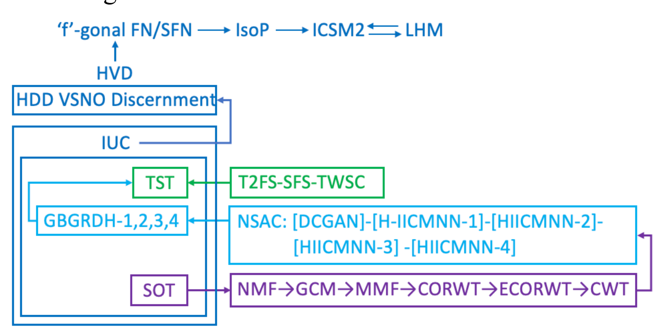


Figure 7. IUC with Constituent Elements [5][14]

The NSAC is a mainstay of the GBGRDH-1,2,3,4 construct, and the utilized SOT progresses from "a Nonnegative Matrix Factorization (NMF) to a Gaussian Composite Model (GCM), which then proceeds to a Multiresolution Matrix Factorization (MMF) that is characterized by its intrinsic ability to ascertain the multiscale structure and appropriately characterize the wavelets for a multiresolution representation" [5][134][135]. This then progresses "to yield MMF's Corresponding WT (CORWT) and the ensuing Enhanced CORWT (ECORWT)," and a "'translation-invariant CWT PyWavelet schema is utilized to implement/transform the ECORWT to the desired CWT' ('which is then used for the wavelet space-based mapping in preparation for HVD')" [5]. This segues to "a more robust IUC," IHP, ACWS, and "MMSO construct" [5]. Fig. 7 depicts the described IUC.

Finally, a review of Section IV is best summarized as follows — the posited construct consists of an interesting amalgam of (1) a LHM, (2) apropos HCM that are data uncertainty-centric, (3) an ICSM2 to gauge similitude, via the discernment of VSNO clusters in HDD (a.k.a., HVD) (wherein HVD is supported by TST), that is informed by the LHM (and vice versa), and (4) a MCDM2, underpinned by an (5) ACWS (operationalized by the MMSO), to leverage entropy weights. The LHM-ICSM2 and MCDM2 should be of no surprise, as they are denoted within the LHM-ICSM2-MCDM2-IFM-AECM-MAM amalgam. The significance of the ACWS and MMSO have been underscored in Sections IC and IVA. Likewise, the import of the HCM and DLC have been previously illuminated in Section IVB. The relationship between HVD and HCM was reviewed in Section IVB, and the role of TST within the IUC was delineated in this Section IVC.

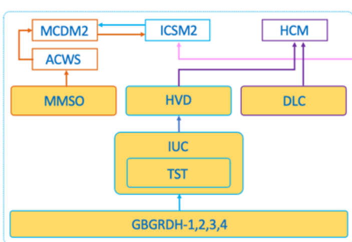


Figure 8. MDCM2-ICSM2-HCM Amalgam with Buttressing Elements [1]

A scrutinization of the GBGRDH-1,2,3,4 architectural construct was conducted to ascertain whether various assertions made in the literature were valid. For example, Medina posited "that the use of Convolutional Neural Networks (CNNs) reduces the False Positive Rate (FPR)" [83][137]. As another example, Moradi asserted that "the use of LSTMs addresses the gradient vanishing issue" [83][138]. The GBGRDH-1,2,3,4 "incorporates these lessons," among others [83]. As in [83], "prototypical ML libraries (e.g., Keras, Scikit-learn, etc.) were utilized," and "experimental variations included PT, Tensorflow (TF), Caffe, Caffe2, and SciPy" [83]. Consistent with various works-in-progress and prior works, "PT and TF" were the preferred implementations. The GBGRDH-1,2,3,4 construct "was evaluated against" other known conventional methods, and a sampling of the "classification results are shown" in Table VIII [83].

TABLE VIII. CLASSIFICATION RESULTS OF VARIOUS ML METHODS [83]

Methods	Models	ACC
"Prototypical ML methods"	"Support Vector Machine (SVM)" [139]	"83.8%" [83]
	"Hidden Markov Models (HMM)" [140]	"87.3%" [83]
	"Random Forest (RF)" [141]	"91.43%" [83]
	"k-Nearest Neighbor (KNN)" [142]	"97.17%" [83]
"Prototypical DLNN methods"	"CNN, CNN Bidirectional (Bi)LSTM hybrid" [143][144]	"93.3-96.2%" [83]
	"RNN, RNN BiLSTM hybrid" [145][146]	"95.5-97.8%" [83]
Posited bespoke GBGRDH-1,2,3,4 construct	GCN-BiLSTM-GAT & RCR-DCGAN-[H-IICMNN]-1,2,3,4	98.4%

Although "N-fold cross-validation," as a classification error measure, "was applied to the" seven "classifiers depicted" in Table VIII, since the utilized schema is rooted in the use of an ACWS, "the subtle intent of cross-validation becomes somewhat moot" [83]. By way of explanation, "if the involved data samples were utilized to train the involved CNN, the ensuing weights and bias values would tend to overfit and segue to 'sub-optimal performance against previously unseen data'" [83]. The standard approach to offset this overfitting "is to separate the data into training data (e.g., 80%) and test data (e.g., 20%)" and settle upon a suitable counterpoising, but the use of ACWS negates this [83]. For the experimentation herein, the more conversative approach of "utilizing an artificially suppressed number of training iterations (as a higher number [of] yields seemingly enhanced performance)," to better emulate an RWS, was adopted [83].

To assess the GBGRDH-1,2,3,4 construct from the vantage point of the "efficacy of [the] RCR, from a layer-wise and overall perspective," Fig. 9 serves as a good reference point.

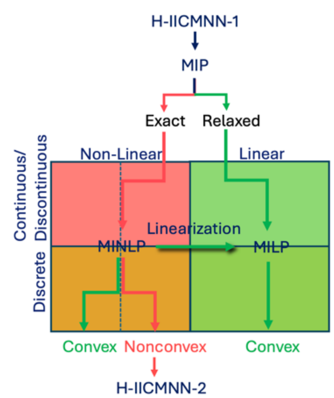


Figure 9. MIP to MINLP and MILP Pathways

When H-IICMNN-1 undertakes its task, the associated Mixed Integer Programming (MIP) can proceed via an exact or relaxed pathway with corresponding verifiers — exact (i.e., complete) or relaxed (i.e., incomplete). Exact verifiers are typically predicated upon Mixed Integer Non-Linear Programming (MINLP), "Branch-and-Bound, as well as Satisfiability Modulo Theories" while relaxed verifiers are "typically predicated upon Mixed Integer Linear Programming" (MILP) "or Mixed-Integer Convex Programming" [83]. In the optimal case, the RCR segues to the depicted green convex pathways noted in Fig. 9. If the RCR inadvertently spawns a Nondeterministic Polynomial (NP)-hard Nonconvex problem, then H-IICMNN-2 is assigned to handle that paradigm. Ultimately, "there are two core aspects of RCR: (1) the actual RCR implemented at each layer," and (2) "the verifier operationalized to ascertain robustness both layer-wise and overall [83][147]. These aspects are "central to the" GBGRDH-1,2,3,4 construct, "which has the counterpoised goals of the tightest possible relaxation" [83][147]. For the experimentation herein, the GBGRDH-1,2,3,4 construct "was able to achieve comparable [Accuracy] ACC to other well-known methods," such as those presented in Table VIII [83]. As in [83], "despite the fact that the posited bespoke method did not achieve the 98.9% rate (with a false positive rate of 4.5%) reported by Alam et al.," the GBGRDH-1,2,3,4 construct exhibits sufficient promise to warrant further examination [83].

V. Conclusion & Future work

The main output of this synthesis paper is that of a posited AI-IS-DE2 construct (i.e., an LHM-ICSM2-MCDM2-IFM-AECM-MAM amalgam) to illuminate desired DEPs; in essence, it introduced an innovative approach that contributed towards the analysis of high-dimensional data and knowledge graph completion. An overarching goal was to contribute to the challenge of discerning VSNO to better and more efficiently (e.g., AEC considerations) perform certain functions, such as AAD/AOSA/CSA as well as IF, for the purposes of DE2. The related goal was to contribute to the challenge of better effectuating STKGC to enhance the discerning of HON. This discernment process included leveraging CENs and CMs (which both help contextualize HON topologies, for which CMs, SCs, hypergraphs, and HPTs lend to transition insights and that of "collective phenomena") for the STKGC task. This discernment of HON not only informs the AAD/AOSA/CSA as well as IF tasks, but also better contextualizes the CS/C2 at play and vice versa. To facilitate the aforementioned, an ACWS to inform STKGC (to affirm the involved CS, HON, and C2) as well as a H-IICMNN approach was used; this approach also assisted in optimizing the model averaging/ensemble used to minimize the AEC. Also, at the core of the IF is the LHM, which is informed by the ICSM2 (and vice versa). In turn, the ICSM2 both informs and is informed by the MCDM2.

The role of the SVs is recapped in Fig. 10, and Section I's Table I may be referenced for the reader's convenience. It illuminates how the SV facilitates the FODM (i.e., MCDM problem) to SOP progression. The SOP can then be resolved to yield the NS, and this then segues to the OSNS. The ICSM2 informs both the FODM (the head of the FODM-SOP-NS-OSNS progression) as well as the OSNS (the tail of the FODM-SOP-NS-OSNS progression). The ICSM2 is underpinned by the IsoP, which is, in turn, reliant upon the IsoP. The IsoP efficacy is dictated by the OCGLfSFN and the P-GLfSFN. The P-GLfSFN to OCGLfSFN progression is facilitated by the involved SimMs/DMs/BD and the ACWS utilized. The ACWS is operationalized by the MMSO and the MA at play.

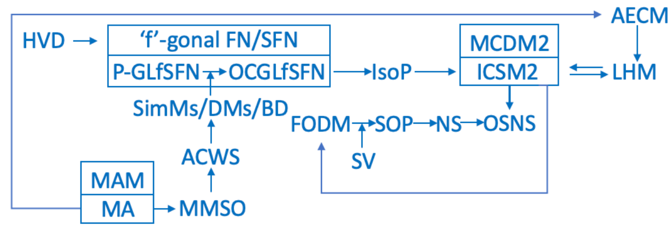


Figure 10. MDCM2-ICSM2-HCM Amalgam with Buttressing Elements [1]

As alluded to in Section IVB Table 5, HVD and HCM are intricately related. Accordingly, only those HCM with reasonable efficacy and low computational complexity were selected. In this way, practical implementation can be effectuated for RWS in a scalable way. This is applied throughout; hence, the integration of multiple bespoke modules does not introduce any unanticipated significant computational complexity (apart from the inadvertent spawning of further NP-hard nonconvex problems from the RCR). Furthermore, not only do the resource demands not necessarily increase, but it can, potentially, contribute towards lessening the resource requirements (e.g., energy) via an energy-aware computing interference-optimized metaheuristic approach, and this was previously discussed in [149].

A. *Principal Contributions*

The generalizability of the proposed approach is high, as it can be applied to the Observe, Orient, Decide, Act (OODA) cycle for various C2 systems. The LHM determines whether further observation is necessary and undertakes the orientation. The MCDM2 undertakes the decision and proceeds accordingly (i.e., facilitates the action). The other modules serve in a support role. For example, the ICSM2 performs the IsoP comparison and informs the LHM. Likewise, the AECM assesses the energy needed/available and informs the LHM. The MAM underpins the IsoP comparison. For the prevalent case of nested MCDMs, the involved MDCM2s inform the IFM, which then feeds into the next MCDM construct. Gomes and other researchers, such as Elmhadhbi, Aqqad, and Zhang note that C2 agility is critical and is "used in a variety of situations, such as disaster response, wildfire management, and power outage mitigation, to mention a few" [4][148][150][151]. They also note that "since decision speed is a crucial parameter, human involvement should be reduced to the Decision and Action phases of the OODA cycle. This segues to the analyses of the involved Socio-Technical System [STS] rubric (which encompasses "humans-in-the-loop"); hence, this affords the opportunity to scrutinize both human and machine biases.

B. Future Work

As Gomes and others note, future "automated systems will likely use concepts, such as" AI "to process incoming data…and present best option[s]" [148]. These future systems are also envisioned to "select optimal networks" (e.g., Opportunistic Networks) and adapt according to the "operational and network status." For critical matters, such as disaster response and wildfire management, shortening decision cycles is vital, and "for this reason, human-machine interaction is a promising topic for future research" with regards to C2 agility [148]. Accordingly, more experimentation regarding the LHM, MCDM2, and related modules seems warranted to advance the areas of information and decision enhancement. Also, more time needs to be spent resolve various signature and dependency issues for certain packages derived from Github and other repositories. To date, this has included implementations in PyTorch, Tensorflow, Caffe, Caffe2, and SciPy.

Acknowledgment

This paper is part of a series of papers under a Quality Control Program (QCP) implemented by the Quality Assurance/Quality Control (QA/QC) unit — attached to the Underwatch initiative of VTIRL, VT — for I-PAC.

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Sarcasm Detection as a Catalyst: Improving Stance Detection with Cross-Target Capabilities

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***Abstract*—Stance Detection (SD) in social media has become a critical area of interest due to its applications in social, business, and political contexts, leading to increased research within Natural Language Processing (NLP). However, the subtlety, nuance, and complexity of texts sourced from online platforms, often containing sarcasm and figurative language, pose significant challenges for SD algorithms in accurately determining the author's stance. This paper addresses these challenges by employing sarcasm detection as an intermediate-task transfer learning approach specifically designed for SD. Additionally, it tackles the issue of insufficient annotated data for training SD models on new targets by conducting many-to-one Cross-Target SD (CTSD). The proposed methodology involves fine-tuning BERT and RoBERTa models, followed by sequential concatenation with convolutional layers, Bidirectional Long Short Term Memory (BiLSTM), and dense layers. Rigorous experiments are conducted on publicly available benchmark datasets to evaluate the effectiveness of our transfer-learning framework. The approach is assessed against various State-Of-The-Art (SOTA) baselines for SD, demonstrating superior performance. Notably, our model outperforms the best SOTA models in both in-domain SD and CTSD tasks, even before the incorporation of sarcasm-detection pre-training. The integration of sarcasm knowledge into the model significantly reduces misclassifications of sarcastic text elements in SD, allowing our model to accurately predict 85% of texts that were previously misclassified without sarcasm-detection pre-training on in-domain SD. This enhancement contributes to an increase in the model's average macro F1-score. The CTSD task achieves performance comparable to that of the in-domain task, despite using a zero-shot fine-tuning approach, curtailing the lack of annotated samples for training unseen targets problem. Furthermore, our experiments reveal that the success of the transfer-learning framework depends on the correlation between the lexical attributes of the intermediate task (sarcasm detection) and the target task (SD). This study represents the first exploration of sarcasm detection as an intermediate transfer-learning task within the context of SD, while also leveraging the concatenation of BERT or RoBERTa with other deep-learning techniques. The proposed approach establishes a foundational baseline for future research in this domain.**

***Keywords*-Stance detection; sarcasm detection; transfer learning; BERT; RoBERTa.**

I. Introduction

This paper extends our previous research on intermediate-task transfer learning, specifically, leveraging sarcasm detection to enhance Stance Detection (SD) [1]. In our prior work, we focused on pretraining models on sarcasm detection before fine-tuning them on SD, utilizing in-domain training data of SD targets. This study further explores SD from two perspectives: in-domain SD, where a single target is used for training and evaluation, and Cross-Target SD (CTSD), which involves training a model on one or more targets and evaluating it on a different target. CTSD represents the latest research direction in this area.

The proliferation of the Internet and social media platforms such as Twitter (X), Facebook, microblogs, discussion forums, and online reviews has significantly altered how individuals communicate and share information [2][3]. These platforms allow users to express opinions and engage with global audiences on various topics, including current trends, products, and politics [4]–[6]. The vast amount of discourse generated on these platforms provides valuable data for Natural Language Processing (NLP) tasks, particularly SD.

SD is the automated identification of an individual's stance based solely on their utterance or written material [5][7]–[9]. Stance refers to the expression of a speaker's or author's position, attitude, or judgment toward a specific topic, target, or proposition [6][10]. Stance labels typically categorize expressions into *InFavor*, *Against*, or *None*. SD has become increasingly relevant in various domains such as opinion mining, fake news detection, rumor verification, election prediction, information retrieval, and text summarization [6][10].

SD research can be broadly classified into two perspectives [6]: detecting expressed views and predicting unexpressed views. The former involves categorizing an author's text to determine their current stance toward a given subject [6][60], while the latter aims to infer an author's position on an event or subject that they have not explicitly discussed [11][12]. Additionally, SD tasks can be categorized as either Target-Specific SD (TSSD) or Multi-Target SD (MTSD). TSSD focuses on individual subjects, whereas MTSD involves jointly inferring stances toward multiple related subjects [5][6][13][38]–[40]. This paper primarily addresses detecting expressed views within the TSSD framework, incorporating unexpressed views through the infusion of sarcasm knowledge into the model framework. Examples of the SD task are provided in Table I.

Previous SD research has primarily utilized publicly available datasets sourced from online platforms [5][6][8][14]. However, texts from these platforms often exhibit subtlety, nuance, and complexity, including sarcastic and figurative language. These characteristics present challenges for SD algorithms in accurately discerning the author's stance [5].

TABLE I
EXAMPLES OF THE STANCE DETECTION TASK

Target	Text	Stance
Feminist Movement	Women don't make 75% less than men for the same job. Women, on average, make less than men. Look it up feminazis. #EqualPayDay #SemST	Against
Feminist Movement	Congratulations to America for overcoming 1 battle for #equality. Now let's have women & all races treated equally #AllLivesMatter #SemST	Favor
Feminist Movement	Honoured to be followed by the truly inspirational Kon__K founder of @ASRC1 #realaustralianssaywelcome #thethingsthatmatter #SemST	None

Moreover, targets are not always explicitly mentioned in the text [7], and stances may not be overtly expressed, further complicating the task of inferring the author's stance. Due to this problem, some examples discussed do not necessarily reflect the authors' beliefs. This often requires implicit inference through a combination of interactions, historical context, and sociolinguistic attributes such as sarcasm or irony.

To address these challenges, prior work has explored intermediate-task transfer learning, involving the fine-tuning of a model on a secondary task before its application to the primary task [2][15]–[19]. For instance, [16] and [19] utilized sentiment classification to enhance their models for SD. Similarly, [2] incorporated emotion and sentiment classification prior to sarcasm detection, suggesting that pre-training with sentiment analysis before sarcasm detection improves overall performance due to the correlation between sarcasm and negative sentiment. This finding aligns with one of our experimental observations in Section IV, where most sarcastic sentences with an "Against" stance are initially misclassified as "InFavor" before incorporating sarcasm pre-training into our model. However, despite its potential, sarcasm has been relatively unexplored as a means of improving SD models. In this study, we experiment with sarcasm detection as an intermediate task tailored to enhance SD performance.

Sarcasm detection involves discounting literal meaning to infer intention or secondary meaning from an utterance [20]. Sarcasm often involves using positive words or emotions to convey negative, ironic, or figurative meanings [21][22]. For example, in the sarcastic sentence "*I like girls. They just need to know their place*," the word "like" is used figuratively to mock the subject, making it difficult for SD algorithms to detect the true stance without accounting for sarcasm. Thus, sarcasm can alter the stance of a text from *Against* to *InFavor* and vice versa if not properly addressed [22][24]. Based on these observations, we developed an SD approach that incorporates sarcasm detection.

This study employs a model framework consisting of BERT [27] or RoBERTa [28], convolutional layers (Conv), a Bidirectional Long Short Term Memory (BiLSTM) layer, and a dense layer. Our experimental results demonstrate the efficacy of this approach, evidenced by improved macro F1-scores when sarcasm detection is included in the model framework. Additionally, we explore the impact of different sarcasm detection approaches on SD performance, considering the linguistic and quantitative attributes inherent in sarcasm datasets. Furthermore, the significance of this approach is underscored through a failure analysis of sarcastic texts from datasets, revealing the limitations of the original SD model before sarcasm pre-training.

We extend the work from [1] by applying CTSD to our tasks using a leave-one-out training approach. This method explores zero-shot fine-tuning on the target of interest, where four targets are used for model training and the remaining one for evaluation. The goal is to transfer knowledge from other targets to the target with limited training examples, thereby circumventing the scarcity of training data and the challenges of annotating sufficient data for new targets [29].

CTSD can be approached in two traditional ways: one-to-one, where one source target is used for training and one destination target for evaluation, and many-to-one, where multiple source targets are used for training and one destination target for evaluation [29]–[32]. The former approach often underutilizes available targets and struggles with generalization to unrelated targets, while the latter addresses these issues but often relies on sophisticated meta-learning approaches and limited datasets have been explored. In this work, we explore the many-to-one CTSD approach on two competitive SD tasks, proposing a solution that integrates sarcasm detection while mitigating the challenges associated with limited annotated SD data through many-to-one CTSD on diverse datasets.

Our experimental results show that the cross-target approach achieves performance comparable to models trained on target-specific data. Further analysis, including correlation measures between training and evaluation targets using cosine similarity on pre-trained language model embeddings, suggests that the overlapping vocabulary between the targets contributes to this performance.

Our work makes the following key contributions:

- *Transfer-Learning Framework:* Introducing a novel transfer-learning framework incorporating sarcasm detection as an intermediate task before fine-tuning on SD, utilizing an integrated deep learning model.
- *Cross-Target Stance Detection:* Introducing the leave-one-out fine-tuning on the SD targets, using four targets in training and the remaining one during evaluation, giving performance on par with training on the latter's desig-

nated data and curtailing the lack of annotated samples for training unseen targets problem.

- *Performance Superiority:* Demonstrating superior performance against State-Of-The-Art (SOTA) SD baselines, even without sarcasm detection pre-training, as indicated by higher macro F1-scores.
- *Correlation Analysis:* Establishing and illustrating the correlation between sarcasm detection and SD, exemplified through a failure analysis, thereby emphasizing the improvement of SD through sarcasm detection.
- *Impact Assessment:* Measuring the impact of various sarcasm detection models on target tasks based on the correlation between linguistic and quantitative attributes in the datasets of the two tasks.
- *Ablation Study:* Conducting an ablation study to assess the contribution of each module to the overall model framework. The study also reveals a significant drop in performance without sarcasm knowledge, underscoring the importance of our proposed approach.

The remainder of this paper unfolds as follows: Section II reviews related work, Section III outlines our proposed approach, and Section IV delves into comprehensive experiments, covering datasets, results, and subsequent discussions. The limitations inherent in our study are critically examined in Section V. The final section provides the conclusion and recommendations for further research.

II. Related Work

This section comprehensively reviews the literature on SD and intermediate-task transfer learning.

A. Stance Detection (SD)

The research on SD has traditionally been explored from two primary perspectives: Target-Specific SD (TSSD), which focuses on individual targets [5][6][33][34], and Multi-Target SD (MTSD), which aims to infer stances toward multiple related subjects concurrently [34][38]–[40]. Early approaches to SD were based on rule-based methods [33][41], followed by classical machine learning techniques [42]–[45]. For instance, [44] applied Naive Bayes (NB) to SD using datasets and features derived from inter-post constraints in online debates. Similarly, [42] utilized features such as unigrams, bigrams, hashtags, external links, emoticons, and named entities in various Support Vector Machine (SVM) models, while [45] employed an SVM model with linguistic (n-grams) and sentiment features to predict stance. In contrast, [43] explored and compared linear SVM, Logistic Regression (LR), Multinomial NB, k-Nearest Neighbors (kNN), Decision Trees (DT), and Random Forests (RF) using the simple Bag-of-Words approach with term frequency-inverse document frequency (tf-idf) vectors of tweets as features for multi-modal SD.

While classical approaches relied on manually crafted features, the advent of deep learning models has seen neural networks gradually replace traditional methods [7][19][46][47]. For instance, the work by [7] investigated SD using Bidirectional Conditional Encoding (BCE) [48], incorporating an LSTM architecture to build a tweet representation dependent on the target. Similarly, [49] employed a CNN for SD, incorporating a voting scheme mechanism, while [16] utilized a bidirectional Gated Recurrent Unit (biGRU) within a multi-task framework that included a target-specific attention mechanism, leveraging sentiment classification to enhance SD performance. Moreover, [46] presented a neural ensemble model combining BiLSTM, an attention mechanism, and multi-kernel convolution, evaluated on both TSSD and MTSD. Although our work shares some similarities in model framework, it uniquely employs BERT or RoBERTa and introduces an intermediate-task transfer learning technique, diverging from ensemble approaches and multi-kernel usage.

Deep learning models necessitate large datasets for effective SD model training and generalization [27]. Consequently, recent research has explored the use of pre-trained language models for SD. For example, [47] proposed using BERT [27] in a cross-validation approach, developing a multi-dataset model from the aggregation of several datasets. Similarly, [5] conducted a comparative study, fine-tuning pre-trained BERT against classical SD approaches, while [34] employed BERT as an embedding layer to encode textual features in a zero-shot deep learning setting, yielding promising results. On the other hand, [33] experimented with ChatGPT, directly prompting the model with test cases to discern stances; however, all these studies reported difficulties in accurately classifying sarcastic examples.

B. Cross-Target Stance Detection (CTSD)

Research on CTSD can be divided into two main approaches. The first is the one-to-one approach, where a single source target and a single destination target share common words, which helps bridge the knowledge gap [29]–[31]. For example, [30] introduced the CrossNet model, utilizing an aspect attention layer to learn domain-specific aspects from a source target for generalization on a destination target. Similarly, [29] used external knowledge, such as semantic and emotion lexicons, to enable knowledge transfer between targets. Meanwhile, [31] explored few-shot learning by leveraging social network features alongside textual content, introducing 300+ training examples from the destination target. This line of research primarily explores related targets within a common domain.

The second approach is the many-to-one method, which involves using multiple source targets for a single destination target. For instance, [32] used many unrelated source targets to the destination target without leveraging external knowledge but instead employed a sophisticated meta-learning approach and did not utilize diverse datasets.

C. Intermediate-Task Transfer Learning

Recent studies have increasingly adopted intermediate-task transfer learning, which transfers knowledge from a data-rich auxiliary task to a primary task [18]. This technique has proven highly effective across various NLP tasks. For example, [15] employed supervised pre-training on four-example intermediate tasks to enhance performance on primary tasks evaluated using the GLUE benchmark suite [50]. Additionally, [19] introduced few-shot learning, leveraging sentiment-based annotation to improve cross-lingual SD performance. Furthermore, [2] employed transfer learning by sequentially fine-tuning pre-trained BERT on emotion and sentiment classification before applying it to sarcasm detection, capitalizing on the correlation between sarcasm and negative sentiment polarity.

To the best of our knowledge, prior research has not explored sarcasm detection pre-training for SD, nor has it investigated the concatenation of BERT or RoBERTa with other deep learning techniques for SD. In this paper, we propose leveraging sarcasm detection for both in-domain SD and CTSD within a model framework comprising BERT, convolutional layers, BiLSTM, and a dense layer.

III. Methodology

This section delineates our approach, covering problem formulation, intermediate-task transfer learning, and the model architecture.

A. Problem Formulation

We denote the collection of labeled data in the source targets as $X^s = \{x_i^s, y_i^s, t_i^{sj}\}_{i=1}^N, j = \{1, 2, 3, ..., k\}$, where x represents the input text, y denotes the stance label, and t indicates the j^{th} target. Here, s represents a source target, and there are k source targets in X^s, comprising N data samples in total. Similarly, we denote the collection of data in the destination target as $X^d = \{x_i^d, y_i^d, t_i^d\}_{i=1}^M, d = \{1\}$, where d represents the destination target, with M data samples. Given an input text x from a destination target t^d, the objective is to predict the stance label of x towards t^d using the model trained on the labeled data X^s. For the in-domain task, $t^s = t^d$; for the CTSD task, $t^s \neq t^d$.

B. Intermediate-Task Transfer Learning

Our approach incorporates intermediate-task transfer learning, which involves two phases: pre-training on an intermediate task and fine-tuning on a target task.

1) Target Task: The primary task in this study is SD, aiming to predict the stance expressed in a given text, such as a tweet, towards a specific target (e.g., '*feminist movement*'). A tweet, denoted as x, is represented as a sequence of words $(w_1, w_2, w_3, \ldots, w_L)$, with L representing the sequence length. Stance labels are categorized as *InFavor* (supporting the target), *Against* (opposing the target), or *None* (neutral towards the target).

2) Intermediate Task: The intermediate task in this study is sarcasm detection, where the goal is to determine whether a given text S is sarcastic. Sarcasm detection labels are categorized as *Sarcastic* (the text is sarcastic) or *Non-Sarcastic* (the text is not sarcastic). As sarcasm has not previously been employed as an intermediate task, we explore three sarcasm-detection datasets to identify key linguistic features that can enhance SD performance:

Sarcasm V2 Corpus (SaV2C). The SaV2C dataset, introduced by [51], is a diverse corpus developed using syntactical cues and crowd-sourced from the Internet Argument Corpus (IAC 2.0). It comprises 4,692 lines containing quote and response sentences from political debates in IAC online forums. SaV2C is categorized into: 1) General Sarcasm (Gen, 3,260 sarcastic and 3,260 non-sarcastic comments); 2) Rhetorical Questions (RQ, 851 rhetorical and 851 non-rhetorical questions); and 3) Hyperbole (Hyp, 582 hyperboles and 582 non-hyperboles). Our focus is on the General Sarcasm category, which includes 3,260 sarcastic and 3,260 non-sarcastic comments.

The Self-Annotated Reddit Corpus (SARC). Created by [52], the SARC dataset contains over a million sarcastic and non-sarcastic statements from Reddit. This dataset features a balanced ratio of sarcastic and non-sarcastic comments, with 1,010,826 training and 251,608 evaluation statements. We utilized the Main Balanced variant, obtained directly from the author of [2].

SARCTwitter (ST). Released by [53], the ST dataset includes 350 sarcastic and 644 non-sarcastic tweets, annotated by seven readers. We used the variant of the dataset employed by [54], which consists of 994 tweets (350 sarcastic and 644 non-sarcastic), excluding eye movement data.

In this work, we implement two levels of transfer learning: first, from sarcasm detection to SD through intermediate-task pre-training; and second, from target-to-target through cross-target fine-tuning. The intermediate-task transfer learning pipeline is illustrated in Figure 1.

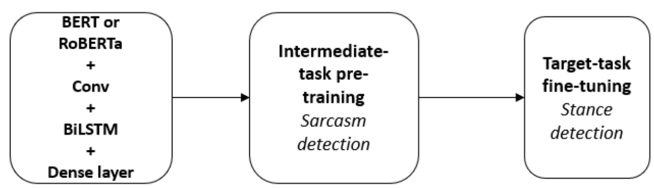

Figure 1. The intermediate-task transfer learning pipeline.

C. Underlying Model Architecture

The model framework consists of an input layer, an embedding layer, and deep neural networks.

1) Input Layer: The input layer processes text x encoding stance information, comprising L words. The text x is converted into a vector of words and passed to the embedding layer.

2) Embedding Layer: We utilize BERT [27] and RoBERTa [28] for encoding textual input into hidden states H. The choice of these language models is supported by their notable performance in the literature [2][5][15][18][47][55].

3) Deep Neural Networks: The deep neural network module includes two convolutional layers (Conv), a BiLSTM layer, and a dense layer, which are applied on top of the embedding layer. The Conv layer identifies specific sequential word patterns within the text, creating a composite feature map from H. This feature map aids the BiLSTM layer in capturing higher-level stance representations, which are further refined by the dense layer. The overall model framework is depicted in Figure 2.

IV. Experiments

This section delineates the datasets employed, details the data preprocessing procedures, outlines the baseline models, presents experimental results, and engages in a subsequent discussion.

A. Datasets

For evaluation purposes, we utilize two publicly available SD datasets: 1) the SemEval 2016 Task 6A Dataset (SemEval) [56], and 2) the Multi-Perspective Consumer Health Query Data (MPCHI) [57].

1) SemEval: The SemEval dataset includes tweets manually annotated for stance towards specific targets, encompassing opinions and sentiments. For our experiments, we utilize tweets and their associated stance annotations. The dataset features tweets related to five distinct targets: Atheism (AT), Climate Change (CC), Feminist Movement (FM), Hillary Clinton (HC), and Legalization of Abortion (LA).

2) MPCHI: MPCHI is designed for stance classification to enhance Consumer Health Information (CHI) query search results. It comprises formal texts extracted from top-ranked articles corresponding to specific web search engine queries. The dataset includes sentences related to five distinct queries, which also serve as targets for stance classification: MMR vaccination and autism (MMR), E-cigarettes versus normal cigarettes (EC), Hormone Replacement Therapy postmenopause (HRT), Vitamin C and the common cold (VC), and sun exposure and skin cancer (SC).

Each text in the datasets is annotated with one of three classes: *InFavor*, *Against*, and *None*. Table II presents the original statistical details of the datasets.

B. Data Preprocessing

We employ standard data preprocessing steps, including case folding, stemming, stop-word removal, and deletion of null entries across all datasets. Text normalization is performed following the method described by [58], and hashtag processing utilized Wordninja [59]. For neural network models relying on pre-trained embeddings, stemming and stop-word removal are omitted, as stemmed forms of terms may not be present in the pre-trained embeddings. The default tokenizer of the respective pre-trained language model is used to tokenize words in tweets prior to inputting them into the classifier.

C. Baseline Models

For the in-domain SD task, we evaluate our model against the top-performing results from the SemEval challenge [60], as reproduced with minor modifications in [5]. Additionally, we compare our model's performance with recent SOTA methods in SD. The following first three baseline models are used for evaluating our model on the in-domain SD task, while the remaining models are used for evaluating the CTSD task.

1) SemEval Models: We select the Target-Specific Attention Neural Network (TAN-) proposed by [61] and the 1-D sem-CNN introduced by [62] from the SemEval competition. Additionally, we include Com-BiLSTM and Com-BERT, implementations provided solely by [5].

2) ChatGPT: The work by [33] explored the use of ChatGPT for SD by directly probing the generative language model to determine the stance of a given text, with a focus on specific targets from the SemEval task: FM, LA, and HC.

3) Zero-Shot Stance Detection (ZSSD): The ZSSD technique [34], which employs contrastive learning, was implemented for the SemEval dataset similarly to ChatGPT.

4) BiCond: An LSTM model that uses bidirectional conditional encoding to learn both input text and target representations for SD [35].

5) TextCNN-E: A variant of TextCNN [36] adapted for the CTSD task by incorporating semantic and emotional knowledge into each word and expanding the dimensionality of each word vector [32].

6) Semantic-Emotion Knowledge Transferring (SEKT): This model leverages external semantic and emotion lexicons to facilitate knowledge transfer across different targets [29].

7) Target-Adaptive Pragmatics Dependency Graphs (TPDG): This model constructs two graphs: an in-target graph to capture inherent pragmatic dependencies of words for a specific target, and a cross-target graph to enhance the versatility of words across all targets [37].

8) Refined Meta-Learning (REFL): A SOTA CTSD model that utilizes meta-learning by refining the model with a balanced, easy-to-hard learning pattern and adapting it according to target similarities [32].

D. Experimental Settings

The experimental setup adopts an inductive approach to transfer learning, where the target task model is initialized using parameters obtained from pre-training on sarcasm detection. This strategy is designed to enhance model performance for the target task. For the intermediate tasks, datasets are divided into training and validation sets solely for sarcasm detection pre-training. Given that Sav2C and ST are the smallest intermediate-task datasets, five-fold cross-validation is utilized for these, while SARC, being larger, employs an 80/20 train/validation split. In contrast, the target task featured a separate test set for final evaluations and comparisons.

Consistent with the methodologies of [5], datasets are divided into training and test sets using similar proportions for in-domain SD, while CTSD employs a leave-one-out strategy. In this approach, data from all source targets are used for model training, and the test data for the destination target is reserved for model evaluation. Each SD dataset consists of five targets; thus, during CTSD experimentation, four targets are used for training, and the remaining target is used for

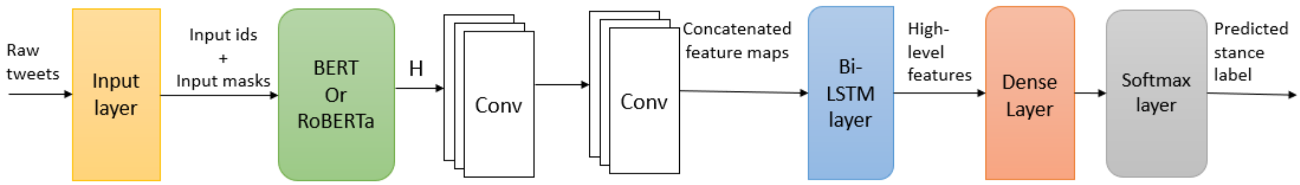

Figure 2. The proposed model framework.

TABLE II
ORIGINAL STATISTICS OF THE DATASETS DIVIDED INTO TRAINING AND TEST SETS

Dataset	Target	Training Samples			Test Samples		
		INFAVOR	AGAINST	NONE	INFAVOR	AGAINST	NONE
SemEval	AT	92	304	117	32	160	28
	CC	212	15	168	123	11	35
	FM	210	328	126	58	183	44
	HC	112	361	166	45	172	78
	LA	105	334	164	46	189	45
MPCHI	MMR	48	61	72	24	33	21
	SC	68	51	117	35	26	42
	EC	60	118	111	33	47	44
	VC	74	52	68	37	16	31
	HRT	33	95	44	9	41	24

TABLE III
STATISTICS OF THE DATASETS AFTER INCORPORATING CROSS-TARGET STANCE DETECTION

Dataset	Target	Training samples			Test samples		
		INFAVOR	AGAINST	NONE	INFAVOR	AGAINST	NONE
SemEval	AT	910	1593	826	32	160	28
	CC	699	2031	767	123	11	35
	FM	766	1546	800	58	183	44
	HC	878	1524	726	45	172	78
	LA	883	1534	761	46	189	45
MPCHI	MMR	314	402	425	24	33	21
	SC	279	417	365	35	26	42
	EC	301	343	376	33	47	44
	VC	276	424	421	37	16	31
	HRT	342	358	453	9	41	24

evaluation. Table III details the statistics of the datasets after incorporating the experimental settings of CTSD.

The Conv layer uses a kernel size of 3 with 16 filters and a ReLU activation function. A BiLSTM layer with a hidden state of 768, corresponding to the hidden state size of the pre-trained language models, is employed. The dense layer has an output size of 3 and utilizes a softmax activation function. All experiments are conducted on an NVIDIA Quadro RTX 4000 GPU.

Hyperparameter tuning involves multiple experiments to select the optimal intermediate-task training scheme based on results from a holdout development set. The best-performing per-task model is then evaluated on the test set. The training process uses a mini-batch size of 16 samples and the Adam optimizer [63], with cross-entropy loss as the cost function. Training epochs ranges from 10 to 50, with early stopping applied if validation accuracy on holdout data plateaus for five consecutive epochs. The learning rate is initially set to 3e-5, decaying to 1e-9 for the intermediate task and 1e-10 for the target task. A dropout rate of 0.25 is introduced between model layers to mitigate overfitting. To address class imbalance, class weights are incorporated during training to improve generalization for underrepresented classes. Experimental setups adhere to the configurations outlined in the original papers for baseline models unless otherwise specified, in which case our experimental configurations are applied.

E. Evaluation Metrics

In alignment with previous studies [5][7][60], the evaluation of our model is based on the average macro F1-score for the *InFavor* and *Against* classes.

F. Results

We first present the results for in-domain SD, followed by the CTSD results. Baseline results for CTSD are referenced from [32]. All results are averaged over five experimental runs per target task.

Table IV displays the experimental outcomes for in-domain SD before the incorporation of sarcasm detection pre-training. Results for ChatGPT and ZSSD are directly transcribed from their original publications, while other baseline results are replicated in our experiments. The table demonstrates the notable performance of our BERT-based model across various targets, achieving superior results in most metrics except HC and CC, where ChatGPT and our RoBERTa-based model excel. Consequently, we select our BERT-based model for subsequent experiments.

Table V reports the results of incorporating sarcasm detection pre-training with our model for in-domain SD. Performance improves by **0.550** on SemEval and **0.003** on MPCHI when pre-training with ST, surpassing all baseline models listed in Table IV. However, performance decreases with Sav2C and SARC. Therefore, subsequent results utilize the ST model.

Table VI presents the results of CTSD. Notably, no baseline models have been evaluated on the MPCHI dataset, focusing instead on SemEval with one target not addressed by the SEKT baseline. Our model outperforms all CTSD models listed in the table on the average macro F1 measure.

Table VII summarizes the results of an ablation study on the in-domain task. Various base model components are systematically excluded to evaluate their contributions to the overall model framework. The model integrating all components—BERT, Conv, BiLSTM, and sarcasm pre-training—achieves the highest average F1-scores of **0.775** and **0.724** on SemEval and MPCHI, respectively.

G. Failure Analysis and Discussion

Following the results presented in Table IV, a detailed failure analysis is conducted to investigate the misclassified test samples. The analysis reveals that misclassifications in the SemEval dataset are predominantly associated with texts containing sarcastic content, consistent with prior findings [5]. This observation supports the rationale for incorporating sarcasm-detection pre-training prior to fine-tuning for SD. Conversely, misclassifications in the MPCHI dataset are primarily linked to samples that contained large, generic health-related facts that are neutral with respect to the target under study. Additional insights derived from the experiments and results across all tasks are discussed below.

1) Performance of Our Model Relative to SOTA Models Without Sarcasm Detection: Our model demonstrates superior performance compared to SOTA models even in the absence of sarcasm detection. Specifically, it outperforms ChatGPT and Com-BERT, which are among the top-performing models, on both SemEval and MPCHI by **0.038** and **0.053** in average F1-scores, respectively, for the in-domain SD task. While Com-BERT utilizes only BERT and a dense layer for classification, our model benefits from additional Conv and BiLSTM layers preceding the dense layer, which contributes to the observed performance improvement. Furthermore, the inclusion of the BiLSTM module in our model results in better performance compared to using pooling layers after the Conv module. This finding highlights the effectiveness of our model architecture in capturing nuanced representations, leading to improved generalization for SD tasks.

2) Correlation Between Sarcasm Detection and SD: An illustrative example of misclassification involves the statement: "*I like girls. They just need to know their place. #SemST*", a sarcastic comment from the FM target in SemEval. The true label for this example is *Against*, but it is misclassified as *InFavor* before the incorporation of sarcasm-detection pre-training. Notably, sarcastic samples in the *Against* class are often misclassified as *InFavor* due to their overtly positive content. After integrating sarcasm detection through pre-training, 85% of these misclassified sarcastic samples are correctly predicted. This result underscores the importance of sarcasm-detection pre-training in enhancing the performance of SD models.

3) Challenges in Using Sarcasm Detection Models for Intermediate-Task Transfer Learning on SD: The integration of SARC and SaV2C knowledge into the model pipeline introduces noise and adversely affects model performance on SD compared to using ST knowledge. Analysis of Sav2C and SARC reveals several discrepancies with the target task. For instance, the average sentence length in Sav2C and SARC is longer compared to SemEval and MPCHI samples. Additionally, SARC is sourced from different domains than SemEval and MPCHI, leading to variations in topic coverage, vocabulary overlap, and the framing of ideas. SARC, being the largest intermediate task, spans a wide range of topics across various subreddits, while ST, which performs best, shares a similar average sentence length with the target tasks and is also crowd-sourced from Twitter (X). This alignment likely contributes to the superior performance observed when using ST as an intermediate task for SemEval. Consequently, the mismatched attributes of certain intermediate tasks can negatively impact model performance. This underscores the need for careful selection and experimentation when choosing a sarcasm model for transfer learning in SD.

4) Performance of Cross-Target Stance Detection: The CTSD task exhibits comparable performance to the in-domain task, despite using out-of-domain data during model fine-tuning. This suggests that our model effectively learns common features from various targets, thereby leveraging this data to perform well on new targets in CTSD. To further understand

TABLE IV
EXPERIMENTAL RESULTS WITHOUT SARCASM DETECTION PRE-TRAINING

Model	SemEval						MPCHI					
	AT	**CC**	**FM**	**HC**	**LA**	**Avg**	**MMR**	**SC**	**EC**	**VC**	**HRT**	**Avg**
Sem-TAN-	0.596	0.420	0.495	0.543	0.603	0.531	0.487	0.505	0.564	0.487	0.467	0.502
Sem-CNN	0.641	0.445	0.552	0.625	0.604	0.573	0.524	0.252	0.539	0.524	0.539	0.476
Com-BiLSTM	0.567	0.423	0.508	0.533	0.546	0.515	0.527	0.522	0.471	0.474	0.469	0.493
ZSSD	0.565	0.389	0.546	0.545	0.509	0.511	-	-	-	-	-	-
Com-BERT	0.704	0.466	0.627	0.620	0.673	0.618	0.701	0.691	0.710	0.617	0.621	0.668
ChatGPT	-	-	0.690	**0.780**	0.593	0.687	-	-	-	-	-	-
Ours-RoBERTa	0.740	**0.775**	0.689	0.683	0.696	0.712	0.692	0.687	0.700	0.701	0.698	0.695
Ours-BERT	**0.767**	0.755	**0.697**	0.704	**0.702**	**0.725**	**0.747**	**0.722**	**0.704**	**0.702**	**0.732**	**0.721**

TABLE V
EXPERIMENTAL RESULTS WITH SARCASM-DETECTION PRE-TRAINING

Task	SemEval						MPCHI					
	AT	**CC**	**FM**	**HC**	**LA**	**Avg**	**MMR**	**SC**	**EC**	**VC**	**HRT**	**Avg**
SaV2C	0.595	0.718	0.596	0.645	0.578	0.626	0.605	0.545	0.545	0.352	0.495	0.508
SARC	0.697	0.612	0.683	0.557	0.641	0.638	0.605	0.545	0.545	0.352	0.495	0.508
ST	**0.769**	**0.800**	**0.774**	**0.795**	**0.741**	**0.775**	**0.749**	**0.727**	**0.704**	**0.703**	**0.739**	**0.724**

TABLE VI
EXPERIMENTAL RESULTS OF CROSS-TARGET STANCE DETETCION WITH SARCASM-DETECTION PRE-TRAINING

Task	SemEval						MPCHI					
	AT	**CC**	**FM**	**HC**	**LA**	**Avg**	**MMR**	**SC**	**EC**	**VC**	**HRT**	**Avg**
BiCond	0.526	0.512	0.527	0.536	0.493	0.519	-	-	-	-	-	-
TextCNN-E	0.534	0.633	0.582	0.591	0.550	0.578	-	-	-	-	-	-
SEKT	0.623	0.600	0.648	-	0.649	0.630	-	-	-	-	-	-
TPDG	0.654	0.667	0.669	0.630	0.600	0.644	-	-	-	-	-	-
REFL	0.650	0.671	**0.734**	0.652	0.623	0.666	-	-	-	-	-	-
Ours	**0.689**	**0.697**	0.730	**0.682**	**0.656**	**0.691**	**0.699**	**0.687**	**0.695**	**0.701**	**0.700**	**0.696**

this observation, cosine similarity scores on the pre-trained BERT embeddings are analyzed. Figure 3 illustrates the cosine similarities between each target and the other targets in their respective datasets. In the figure, LAMMRSC should read as LA, MMR, and SC on the X axis. The figure demonstrates that all targets share common vocabulary with others, leading to shared features. Additionally, MPCHI targets have higher cosine similarity scores than SemEval targets, which aligns with the superior CTSD performance observed on the MPCHI task.

5) *Ablation Study on Sarcasm Knowledge:* The results of the ablation study presented in Table VII provide insights into the contribution of each module and the overall impact of sarcasm detection pre-training on SD performance. Comparing the results in Table IV and Table VII, the incorporation of sarcasm knowledge significantly enhances model performance on the SemEval task compared to the MPCHI task. SemEval includes a large volume of opinionated and sarcastic texts, whereas the MPCHI dataset primarily consists of health-related facts, with occasional sarcastic expressions. As a result, there is a modest improvement in performance on MPCHI when sarcasm detection is used. This suggests the potential for exploring BERT or RoBERTa embeddings pre-trained

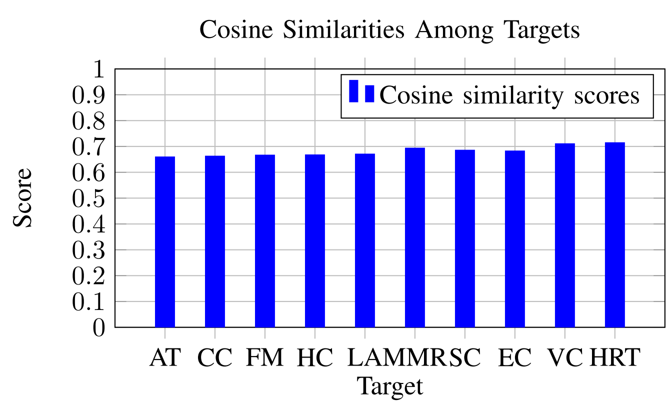

Figure 3. Cosine similarity scores for each target in comparison with other targets within their respective datasets.

TABLE VII
EXPERIMENTAL RESULTS OF AN ABLATION STUDY

Model	SemEval						MPCHI					
	AT	CC	FM	HC	LA	Avg	MMR	SC	EC	VC	HRT	Avg
BERT	0.674	0.677	0.678	0.609	0.685	0.665	0.568	0.519	0.441	0.482	0.595	0.521
BERT+Conv+BiLSTM	0.767	0.755	0.697	0.704	0.702	0.725	0.747	0.722	**0.704**	0.702	0.732	0.721
ST+BERT	0.712	0.735	0.698	0.687	0.696	0.706	0.687	0.601	0.540	0.466	0.546	0.568
ST+BERT+Conv	**0.770**	0.759	0.689	0.683	0.694	0.719	0.458	0.535	0.479	0.350	0.524	0.469
ST+BERT+BiLSTM	0.747	0.765	0.675	0.657	0.678	0.704	0.640	0.618	0.573	0.528	0.633	0.598
ST+BERT+Conv+BiLSTM	0.769	**0.800**	**0.774**	**0.795**	**0.741**	**0.775**	**0.749**	**0.727**	**0.704**	**0.703**	**0.739**	**0.724**

on health-related data specifically for SD on MPCHI as a promising avenue for future research.

V. LIMITATIONS

Despite the significant contributions of this study to NLP in social media contexts, several limitations warrant consideration. Firstly, the extent of model performance improvement is dependent on the characteristics of both the intermediate sarcasm detection task and the ultimate SD task. Variations in linguistic features across datasets used for sarcasm detection and SD may limit the generalizability of the study's findings. Secondly, while the integration of BERT or RoBERTa with other deep-learning methodologies represents an innovative approach, the complexity of the model architecture may pose challenges in terms of computational resources and interoperability in certain contexts. Thirdly, the CTSD task presents additional challenges, as the language models employed may not be compatible across different targets. Lastly, the heavy reliance on fine-tuning techniques and specific datasets raises concerns about the model's ability to generalize effectively across diverse text types or domains not covered within the training data.

VI. CONCLUSION AND FUTURE WORK

In this study, we have proposed a transfer-learning framework that integrates sarcasm detection for SD. We have utilized pre-trained language models, RoBERTa and BERT, which have been individually fine-tuned and subsequently concatenated with other deep neural networks, with BERT demonstrating particularly promising results. The model has been pre-trained on three sarcasm-detection tasks before being fine-tuned on two target SD tasks. Our evaluations, including in-domain SD and CTSD, have shown that our approach outperformed SOTA models, even before incorporating sarcasm knowledge. The correlation between sarcasm detection and SD has been established, with the integration of sarcasm knowledge significantly enhancing model performance; notably, 85% of misclassified samples in the SemEval task have been accurately predicted after incorporating sarcasm knowledge. Failure analysis has indicated that the SemEval dataset, rich in opinionated sarcastic samples, has benefited significantly from sarcasm pre-training, in contrast to the MPCHI dataset, which primarily consists of generic health-related facts. Furthermore, our study has revealed that not all intermediate sarcasm-detection tasks have improved SD performance due to mismatched linguistic attributes. Additionally, the CTSD task has demonstrated performance on par with the in-domain task despite using a zero-shot fine-tuning approach, effectively addressing the issue of limited annotated samples from new targets. Finally, the ablation study has highlighted that the optimal performance of the model is achieved when all components are utilized.

To the best of our knowledge, this work represents the inaugural application of sarcasm-detection pre-training within a BERT (RoBERTa)+Conv+BiLSTM architecture before fine-tuning for SD. Our approach serves as a foundational reference, setting a baseline for future research in this domain. Future work will explore variant BERT or RoBERTa embeddings tailored to health-related text data for the MPCHI task and will focus on a more comprehensive evaluation of other intermediate tasks, including sentiment and emotion knowledge.

ACKNOWLEDGMENT

This work is supported by the National Science Foundation (NSF) under Award number OIA-1946391, Data Analytics that are Robust and Trusted (DART). We sincerely thank our anonymous reviewers for their valuable insights and constructive feedback. Additionally, we extend our gratitude to all individuals who contributed to this study in various capacities.

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The Challenges of Producing and Integrating Accessibility Data as Stumbling Blocks for Seamless Travel Chains in Public Transportation and MaaS for All

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***Abstract*—This extended article presents the challenges that people with mobility and functional disabilities face in seamless travel chains of public transport and in Mobility as Service (MaaS) conceptualized solutions. Building upon our previous research presented at The Ninth International Conference on Universal Accessibility in the Internet of Things and Smart Environments SMART ACCESSIBILITY 2024, we explore how these challenges act as stumbling blocks in achieving truly inclusive mobility solutions. The study emphasizes that while transport accessibility for all is considered essential, passengers with temporary or permanent disabilities continue to face significant barriers. We investigate the complexities of creating both physically accessible environments and digitally accessible information systems, highlighting the increased difficulty when aiming to integrate various modes of transport into customized, seamless travel chains via MaaS platforms. The research conducted in the city of Riihimäki in Southern Finland and its surrounding areas maps the key accessibility information needs of people with various mobility and functional disabilities. We compare these needs against the accessibility information provided by official travel databases, including National Access Points (NAP). The study examines common standards for data sharing and the challenges operators face in data production and integration. The findings reveal that although essential accessibility information can be found in databases, it often remains inaccessible or is not available in MaaS conceptualized route guides. We identify multiple reasons for this data accessibility gap and propose areas for improvement in the current system. Furthermore, this extended version explores the integration of accessibility data into MaaS platforms, discussing both the challenges and opportunities this presents for creating truly seamless and inclusive travel experiences. We also consider the role of emerging technologies and universal design principles in overcoming these obstacles. By providing a comprehensive analysis of the challenges in accessibility data production and integration, this research offers valuable insights for policymakers, transport operators, and technology developers. The goal is to foster the development of more inclusive public transport systems and seamless travel chains, ultimately improving the travel experience for all users, regardless of their skills.**

Keywords-accessibility; barrier-free transportation; public transportation; travel chain; public transportation for all; digital accessibility; MaaS.

I. INTRODUCTION

This article is an extended version of the conference paper titled "Challenge of Producing Accessibility Data for Public Transport and Travel Chains" [1], which was presented at The Ninth International Conference on Universal Accessibility on the Internet of Things and Smart Environments (SMART ACCESSIBILITY 2024) in May 2024.

Transport accessibility for all is considered an essential right for a more equitable and fair society [2]. Accessibility refers to the physical environment, e.g., buildings, roads, stops, intersections, parks and other places, services, means of transport, etc. An accessible environment is a space that entitles everyone to free and safe movement, activity, and access, regardless of age, gender, or ability to function. It is about the extent to which the diversity of people is considered in the planning, implementation, and maintenance of the built environment. An environment, building, bus stop or train stop, or means of transport is barrier-free when it is functional, safe, and pleasant for users, and when all facilities are easy to access. In a barrier-free environment, the spaces and their functionality should be as easy to use and logical as possible. Barrier-free environments together with accessible services, usable tools, and comprehensible information realize equal inclusion. A universal design perspective intends to ensure the design and composition of an environment are achieved in such a way that it can be accessed, understood, and used to the greatest extent regardless of age, size, or ability. When spaces are designed to accommodate diverse needs from the outset, it benefits everyone—whether they have a disability or not.

According to the United Nations [3], sustainable transport aims to promote general accessibility, better safety, reduced environmental impact, flexibility, and greater efficiency. Sustainable transport is also expected to have effects on eradicating poverty, increasing equality, and combating climate change. In cases when the infrastructure, systems, and services are missing or are inadequate, the benefits of transport cannot be accessed. For example, remote rural areas are especially disadvantaged, as they often have poor links to regional and national transport networks. In some cases, the transport infrastructure and systems do exist, but they still fail to provide safe and convenient access for older persons and Persons with Disabilities (PwDs).

The European Union's Sustainable and Smart Mobility Strategy (2020) [4] aims to create a sustainable, inclusive, and resilient transport system that benefits everyone while addressing environmental challenges and embracing technological advancements. It emphasizes a smart, competitive, safe, accessible, and affordable transport network. According to the strategy, the principle of "No-one is left behind" underscores the commitment to create a transport system that serves everyone, promotes equity, and enhances the quality of life for all individuals across the European Union.

The Intelligent Transport Systems (ITS) Directive 2010/40/EU [5] and its Delegated Regulations require that each European Member State must establish a National Access Point (NAP) for mobility data. It aims to encourage the development of innovative transport technologies to create the ITS. It is part of a broader initiative to enhance connected mobility experiences in Europe. It serves as an open national gateway where mobility service providers must submit information about their digitally accessible essential data interfaces. NAP is not a service for end-users or passengers; rather, it is intended for mobility service providers and developers.

In Finland, the Act on Transport Services (643/2017) [6] obliges all transport operators to share information about their own services for the use of other operators in the sector. Data is shared through interfaces. Such interfaces are used to transmit information between two systems. Information on open interfaces is exported and compiled in the Finnish Transport Agency's NAP service catalogue [7]. The provider of mobility services for passenger transport must ensure that essential and up-to-date information regarding the mobility service is also available in a machine-readable format. Opened data is used for making route guides and traffic services, for example. The relevant information varies by service type. For example, there are two obligations to share interfaces concerning the municipal sector. The obligation to provide essential information applies to all providers of passenger transport mobility services, regardless of the mode of transport. This information concerns aspects such as, the route, stops, schedule and price information, as well as information about the availability and accessibility of the service. Another only those entities that have a ticket and payment system.

An estimated 87 million Europeans currently have some kind of permanent disability or temporary obstacles to movement or functioning [8][9]. In Finland, the number of people with various disabilities is estimated to be slightly less than 19% [10]. Whether it is a question of permanent or temporary obstacles to movement and functioning, obstructed infrastructure, inadequately guided routes, and insufficient digital travel information make traveling difficult. Public transport use and barriers to this use may be experienced differently by people with various types of disability, e.g., physical, sensory, or cognitive. To understand the various functional needs, these can be roughly categorized as follows: (1) *physical or motor disabilities* cause muscle weakness, balance difficulties or mobility limitation in physical movements, which in turn result difficulties walk, climbing the stairs, opening heavy doors; (2) *visual impairment* can vary from colour blindness, low vision to complete loss of sight in one eye or both, which causes difficulties navigating, visualizing spaces and seeing directional signs and other visual information; (3) *auditory disability* or hearing impairments can vary from low to complete hearing loss in one ear or both, resulting in difficulty hearing spoken language and auditory information; (4) *cognitive or learning difficulties*, affect understanding and memorization of instructions and texts; (5) a*ging*, can cause varying degrees of weakness in movement, sensory and cognitive functions; and (6) *temporary difficulties in movement, sensory or cognitive functions* caused by accidents, medicines or diseases, may limit movement in traffic [11][12]. Passengers with temporary or permanent disability of movement or function face difficulties using public transport services. Taking these aspects into account to build a physically accessible environment and to produce digitally accessible information from the former have proven to be demanding.

The challenge becomes even more demanding when the goal is to make the entire travel chain physically barrier-free and to combine different forms of movement into customized, seamless travel chains, with a digital delivery system via a single connecting service—Mobility as Service (MaaS) [13]. The characteristics of MaaS include the integration of multiple transport modes, various payment options, and the use of various technologies enabling the use of a single interface and platform while catering for personalization and customization to offer user-centric mobility services [14]. The origins of the MaaS can be found in ITS. MaaS is intertwined with the development of a sustainable transport system as a whole [15].

Currently, the literature on the barriers found in the built environment, on public transport and travel chains can be found relatively well [13][16]. On the other hand, there is very little literature about the type of information available on the environment and the public transport and travel chain and how this information is made available or used to serve the needs of PwDs. In addition, no literature is available on how the accessibility perspective of travel chains has been implemented in practice as part of MaaS services, e.g., in route guides. The final report of the Ministry of Transport and Communications in Finland (2022) [17] finds that at the national level, accessibility has not been considered much in Finland's first MaaS service pilots, and the measures to promote the accessibility of MaaS services have not been sufficient. To respond to this gap in the literature, this study aims to examine what kind of essential accessibility information is offered and how it corresponds to the critical essential accessibility information needs experienced by PwD in relation to the travel chain.

The content of the article is structured as follows. In Section II A, we examine what is meant by the travel chain and how the different stages appear to the passenger, as well as what is meant by the officially defined essential accessibility information of the travel chain. Section II B reviews MaaS services possibilities and challenges for implementation, legal, and user behaviour point of view. Section II C examines the accessibility of the travel chain in the light of previous literature. Section III describes the methodology used, the research area, the research object, the research participants, and the data collection process. In the results of Section IV, A, the critical accessibility information of the travel chain identified by PwDs during the planning phase of the trip and during a trip is discussed. Section IV B examines essential accessibility information identified from data sources and compares it with accessibility information defined as critical by PwD. Section V considers the development aspects of perceived and official essential accessibility information based on the results, and Section VI concludes the results regarding how the results can be used in the development of accessibility information for public transport travel chains.

II. TRAVEL CHAIN AND BARRIERS

A. *Accessible Travel Chain and Essential Accessibility Information*

When designing and planning public transport, travel chains, and built environments, it is critical to consider accessibility and the needs of all potential users. A travel chain refers to a journey from point A to point B, which may consist of one or more different means of transport [18]. Ideally, it should be possible to arrange and pay for entire travel chain from one service provider. The travel chain may also have hubs, e.g., travel centers and train stations, where passengers change from one means of transport to another. In the optimal case, the passenger gets the mobility services she/he needs from door-to-door based on the principle of one payment and one ticket. The transport services are meant to work together seamlessly for all passengers, and real-time information about the progress of the journey is also available during the trip.

An accessible travel chain can be defined as a continuum consisting of accessible services, physically accessible, and multi-sensory guided routes, stops, means of transport, and station spaces, which enable all passengers to travel as independently, smoothly, and barrier-free as possible.

What is meant by the essential accessibility information of travel chain? According to the EU’s directive (2019/882) [19] and the Act on Transport Services (107/2023) [20], essential accessibility information refers to information in digital form provided on websites and mobile applications about available services and assistance, in addition to intelligent ticketing systems, accessibility of the infrastructure and built environment surrounding the transport services, accessibility of equipment, equipment that facilitates the passenger's access to vehicles, available interaction with the driver, and access to real-time travel information.

B. *MaaS Possibilities and Challenges*

The digitization and proliferation of Mobility as a Service (MaaS) are expected to create new user-oriented opportunities, paving the way for the development of universally designed transport services [13][21]. MaaS is defined as "A type of service that, through a joint digital channel, enables users to plan, book, and pay for multiple types of mobility services" [13]. Originating from Intelligent Transportation Systems (ITS) [22], MaaS is intricately intertwined with the development of sustainable transport systems as a whole.

MaaS platforms aim to integrate multiple transport modes, various payment options, and diverse technologies, offering user-centric and user-sensitive mobility services through a single interface. While the goal is to make travel chain services accessible to everyone, several concerns arise. The increasing digitization of service sales and information provision may exclude some passengers who lack digital skills or whose access to digital devices is limited. Ensuring that accessibility information about mobility services and transport infrastructure is effectively transferred from information administrators to MaaS operators and ultimately to passengers remains a challenge [23]. As mobility services and their purchase become increasingly dependent on online platforms, there's a growing need for these digital services to be accessible to all users, including those with disabilities and rather modest digital skills. With new actors emerging between customers and transport operators, it's crucial to maintain up-to-date databases that convey comprehensive accessibility information about the entire travel chain to customers.

The creation of MaaS across different regions faces numerous challenges spanning technical, regulatory, economic, and social dimensions. Essawy (2024) highlights the challenge of diverse data formats used by different transport operators and regions, making seamless integration into a unified system difficult [15]. Ydersbond et al. (2020) point out that many existing transport systems rely on outdated technology, which is not easily compatible with modern MaaS platforms and unsuitable for integration [24]. Technical infrastructure varies significantly across regions. Ydersbond et al. (2020) note the substantial disparities in digital infrastructure between urban and rural areas, affecting the uniform implementation of MaaS [24]. Russo (2022) emphasizes that many transport systems lack the capability to provide real-time data, which is crucial for effective MaaS operations [25]. User adoption and behavioral change present further challenges. Silvestri (2021) observes that many users are accustomed to traditional transport modes and may be reluctant to switch to a new, integrated system [26]. Essawy (2024) adds that varying levels of digital literacy among different demographic groups can affect the adoption of MaaS platforms [15].

From a political and public sector perspective, the implementation of MaaS faces additional challenges. Public sector discussions and negotiations regarding service integration and contracts are often time-consuming processes. However, the complexity of integrating various transport modes, payment systems, and applications within this framework presents significant challenges. For instance, during a typical 15-minute city trip, users might need to switch between multiple applications and transport modes, raising questions about seamless integration, user experience, and payment methods.

When MaaS offers significant potential for improving mobility and accessibility, its successful implementation requires addressing a complex array of challenges. These range from technical and infrastructural issues to user adoption and accessibility concerns, as well as political and economic considerations. The integration of MaaS into city necessitates a comprehensive, inclusive approach to development and deployment, involving close collaboration between public and private sectors to create systems that are not only technologically advanced but also equitable, sustainable, and aligned with broader city development goals.

C. Barriers to Passengers' Movement and Functioning in the Travel Chain

Concerning accessibility in travel chains, Mwaka et al. (2024) [15] reviewed 34 articles on the subject to identify physical and social barriers, and facilitators in the travel chain, and to highlight issues related to lack of confidence or self-efficacy and reduced satisfaction when PwDs and older adults were using public transport. The results are organized in relation to the phases of the travel chain. The most common barriers found by the authors are described in the following. (1) *In relation to travelling to or from a public transport stop or station* were long walking distance, irregular walking surfaces, narrow pathways, branches hanging in pathways, small holes, poor design of curb cuts, difference in levels, steep side gradients on pathways, low contrasts in surface changes, combined pedestrian and cycling lanes, grey posts on pathways, crossings with traffic lights but no auditory signals, short walking times for crossings at traffic lights, traffic from two directions, turnstiles without sound modules to provide information about remaining balances on travel passes, crossing busy streets, lack of sidewalks, road works, lack of pavements, and a lack of low curbs. The most common barriers (2 In relation to waiting at the stop or station information was found to be unavailable in terminals or bus stops, drivers did not stop to let people board the bus, there was poor platform design and lack of signage, or signage too bright and glargine, there were levels of noise, lack of visual announcements on trains, narrow bus stops, no weather protection or shelters, no seats or inadequate seats, many buses stopping at the same bus stop, lack of timetables, small text on timetables, poor visibility on monitors, incorrect information, difficult to interpret information, no information about routes in service, no information provided in braille, the presence of stairs in railway stations, broken elevators or escalators. (3) *In respect to boarding and getting off the public transport*, the most common barriers were related to ramps, including lack of ramp, inoperable ramps, steep slope for ramp use, and ramp deployment angle (≥9.5°). (4) *In respect to the public transport vehicle*, the most common barriers related to the presence of steps at the vehicle entrance. (5) *Other common issues related to public transport use* included inability to navigate public system, lack of confidence in the use of public transport, lack of knowledge of public transport network, and fear of injury related to public transport.

III. Methodology

A. Identifying the Research Question

The research question of the study is to examine what kind of essential accessibility information on public transport travel chains is offered and how it is offered, as well as how the information meets the accessibility information needs of people with various mobility and functional disabilities.

The research is conducted in three phases, and each has its own target. (1) The first phase focuses on mapping the accessibility of mobility services, service processes, travel chains and hubs from the point of view of persons with temporary or permanent impairments, with the target of acquiring knowledge about what kind of accessibility information about the public transport travel chain is offered and how. (2) Based on the mapped results, the second phase focuses on defining the critical accessibility information about mobility services, service processes, nodes and infrastructure included in the travel chain from the user perspective and in relation to official sources of essential accessibility data. (3) The third phase identifies the actors within the MaaS architecture responsible for facilitating barrier-free movement in the city and region of Riihimäki. This phase focuses on study group used applications. This article reports on the results of these three phases, along with insights gained regarding the use of smartphones by PwDs when accessing public transport services.

B. Description of Study Area and Participants

The case study takes place in southern Finland, in the City of Riihimäki and the region. Riihimäki, has 30,000 inhabitants, and is a typical medium-sized city in Finland. As such it is an example of availability of accessibility information concerning the travel chain is realized in a smaller city, like most Finnish cities. Its distinctive features, however, are that it has a dense urban structure and a busy train station. The entire station-zoned urban area is within a three-kilometer radius of the railway station, where 97% of the population lives. Riihimäki has a Sustainable Mobility Program [27], with significant investments in the urban environment to increase sustainable modes of transportation. Sustainability refers to environmentally and socially favorable modes of transportation that are economical, smooth, safe and improve the health of the person moving. City dwellers are encouraged to use sustainable modes of transportation, such as walking, cycling, using public transport and travel chains, as well as carpooling.

The public transportation consists of regular local bus lines, small on-demand buses with door-to-door services, service lines on standard routes and taxi services for disabled. All local and on-demand buses have low floors. The most important hubs are the railway station, the bus station, and the expressway connection to regional buses. There is interconnectivity between the hubs and regions. Regional and local buses, including on-demand buses, feed regional, long-distance, and international trains.

Public transport uses a mobile application and an online version of the route application *Routes and Tickets* to reserve and pay for tickets and travel chains. The application can also be used to report transport needs for wheelchairs, strollers, and rollators. In addition, there is an option to reserve and purchase tickets by phone. Another route guide in use on the Internet and as a mobile application, especially for travel chains including train journeys, is provided by *VR Matkalla*.

The primary target group of the study are persons with temporary or permanent mobility and/or sensory challenges due to illness, aging, and/or disability (PwD). A sample of thirteen volunteer representatives of the target group from local and national disability organizations participated in the study.

TABLE I. TARGET GROUP

Target group deviation for different diseases and conditions			
Disease/Condition	***Count of PwDs***	***Assistive Devices/Services***	***Information and Communication Technology***
Physical or motor disability	7	Wheelchair (1x), Occasional Electric Wheelchair (1x), Electric wheelchair (4x)	Computer, Smartphone
Visual impairment, Blindness	3	White cane (3x), Guide dog (1x)	Computer, Smartphone
Visual impairment, Low Vision	2	None	Computer, Smartphone
Aging with Temporary physical difficulties	3	Assistant	Computer, Smartphone

The mobility challenges faced by PwDs are highlighted in Table I, which summarizes the diseases and conditions affecting them. This table provides a comprehensive overview of the study's sample, showcasing the diversity of conditions and challenges encountered. In addition, the material shows the differences due to disability and functional capacity in relation to aids and services used by PwDs and information and communication technologies. The age range of participants was 40-82 years. Thirteen of the participants currently use public transport independently and two with the accompaniment of another person.

All the participants had computer and Internet access at home, and owned a smartphone, but their skills in terms of searching for information on the Internet as well as using a smartphone varied. Another indirect target group are public transport authorities, operators, companies, and associations that provide mobility services in Riihimäki and the region.

C. Data collection

To define the necessary essential information, from the point of view of a PwD, information was needed on which accessibility information is perceived as usable and useful before and during the trip. Data collection took place between February 2023 to December 2023 (around eleven months). The data collection was carried out using the snowball sampling method. For participants to be eligible, they had to be current public transport users. Local and regional disability councils and organizations representing disability groups were contacted to invite their members who matched the criteria to participate. Organizations were given email addresses and phone numbers so that potential participants could contact the researcher directly, or the volunteers' contact information was provided to the researcher, who contacted then the volunteer. Once an individual participated, they were asked to invite other people they knew. This approach ensured potential participants of the research through personal endorsements.

The goal was to recruit at least 12 participants so that the thematic saturation of the information and the validity of the data were realized [28]. Small samples have been found to be quite sufficient in providing complete and accurate information within a particular cultural context, as long as the participants possess a certain degree of expertise in the domain of inquiry [29]. The individuals in our purposive sample shared common experiences, and these experiences comprise perceived and experienced truths. PwDs talked about the challenges of finding necessary and accurate accessibility information regarding routes, junctions, and vehicles related to their travel chains during the planning phase. For example, they questioned whether the elevator at junctions would be functioning. Fear and distrust of data concerning a seamless travel chain are realities in the daily lives of PwDs and are thus reflected in the data.

The data collection was originally planned to be carried out through a self-administered online user preference survey, developed by using the online survey tool Forms by Microsoft. After the first workshop organized for visually impaired people, it was obvious that simply answering the survey independently online would not be a sufficient way to collect the data. Due to reported difficulties with the use of computers by the participating PwDs thematize interviews based on original questionnaire were implemented.

Planning the travel chain (1): The first phase of the research began by examining how the participants typically planned a journey chain before traveling. The travel chain consisted of leaving from the origin of the journey to the destination with the required vehicle exchanges at hubs. The thematic interviews and travel chain planning were done in eight workshops. At each workshop, the participants explained their travel chain planning processes and justified their choices. During the discussions, the researchers asked the participants clarifying questions as needed. All conversations were recorded. The content of the recordings was analyzed using content analysis methods. Each volunteer participated in 2-6 workshops and interviews, depending on the number of trips they made. Planning was done on the Internet with a focus on access to passenger accessibility information, available information about barrier-free mobility services, service processes, and accessible vehicle exchanges at hubs. The purpose was to understand the methods PwDs used to search for accessible travel information and how they accessed the different information they required through various digital tools, websites, or by calling customer service.

On the journey implementation (2), data was collected by retrospectively recalling the step-by-step implementation of the trip, and by observing the implementation of the trip with jointly realized trip chains. These observations were collected during thematize interviews, by reading travel diaries, and by implementing a variety of monitoring methods, e.g., shadowing, and passive observation, during field journeys, and after the journey with theme interviews based on recalling the travel experiences retrospectively from the entire travel chain including the various transport nodes. In connection with the workshops, essential accessibility information was also defined from the perspective of PwDs. Observations and thematic interviews in connection with the workshops were used to find out how accessibility information was present when PwD passed through the different stages of the travel chain and where the problem areas in terms of accessibility were. PwDs, the authorities and other stakeholders were invited to a joint seminar at the end of this data collection phase, where the results were presented, and the views of all parties, and conclusions from the results were heard. The aim of the seminar was to deepen the common understanding of accessibility information needs and strengthen the reliability of the results.

The second phase of data collection compared the mapped critical essential accessibility needs with the officially defined accessibility information standards. To enable a comparison, the official data sources in use were assembled by interviewing stakeholders and authorities responsible for the data sources. Comparing these elements began in the workshops after the actual journey experiences of the PwDs. The most critical accessibility information of PwDs' travel experiences, the mobility services, service processes, stops, vehicles and vehicles exchange at nodes, and multisensory guidance were analyzed. The identified essential accessibility information needs were compared with the information available through route guides and with the official digital data sources behind them. A second seminar with the same purposes was organized at this point and thus all concerned contributed to the analysis process.

In the third phase of our study, we evaluated services that integrate multiple data sources to facilitate travel chain planning and identify suitable travel options for PwDs. These services were examined as MaaS solutions, which are essential for making travel chains more accessible and easier to navigate for all users, particularly those with disabilities.

Our research emphasizes the crucial role of integrating MaaS with NAPs. NAPs should serve as comprehensive repositories of transportation information for various cities, providing a solid foundation for MaaS services. This integration is a critical factor in enhancing the usefulness and effectiveness of MaaS solutions, ensuring the seamless incorporation of diverse data sources.

To gather relevant information, we focused on services actively used by our target group of PwDs. Our methodology involved a thorough examination of each application's accessibility features and an analysis of how PwDs utilize these services in their daily lives. This approach allowed us to gain valuable insights into the practical usability and effectiveness of MaaS solutions for users with various disabilities.

When evaluating the real-world application of these services, we aimed to identify both the strengths and areas for improvement in current MaaS offerings. This user-centric approach provides a more nuanced understanding of how well these services meet the specific needs of PwDs and highlights potential areas for future development in making travel more inclusive and accessible.

IV. RESULTS

A. *Experienced challenges of the travel chain*

During the analysis process, the results from the questionnaires, theme interviews, workshops, observations, and experiences from physical excursions were classified based on the content and theme (Table II). This table provides a comprehensive overview of all the information gathered during the different phases of the travel chain.

TABLE II. CHALLENGES IN THE TRAVEL CHAIN

Challenges of travel chain phases	
Preliminary phase	***Implementation phase***
Travel booking challenges	The challenges of means of transport
Challenges of needed accessibility information of routes, junctions, and vehicles	The need for information while traveling
Lack of customer services and challenges of assistance services	The challenges of assisting
The challenges of reserving, buying, and getting hold of a ticket	The challenges of nodes

During the trip planning phase, the need to reduce various uncertainties regarding the trip was highlighted. Travel booking challenges of the preliminary phase were related to the selection of the most suitable route options, and vehicles' choices, as well as keeping the number of hub changes as few as possible. Optimal choices of the travel chain were made based on available accessibility information, e.g., train trips were preferred instead of long distance buses, and the distance was important between the arriving and departing platforms at transport nodes. Other important aspects, included finding a suitable ticket for journeys and purchasing it easily, allowing enough time for vehicle changes at nodes, providing sufficient information about vehicle accessibility, and information about assistance services. These elements were considered crucial for ensuring a sense of safety while traveling. The most important aspect discussed by the interviewed PwDs was traveling safety provided by the preliminary information which was seen as lacking in many cases.

During the implementation phase, identified critical needs included the availability of assistance service points, certainty of assistance, and access throughout the entire travel chain. It is crucial to consider how to access information in case of unexpected changes in the travel chain. Tracking the progress of the trip, tactiles, multisensory guidance, and sound beacons were recognized as essential for individuals who were blind or visually impaired.

B. Narrow view of essential accessibility information in data sources

Accessibility data was examined through various data sources and was utilized to gather information to analyze different interfaces. The formats of these sources vary, impacting how the data is presented for diverse uses and its accessibility in machine-readable formats. This study concentrates on accessibility information which is, typically available on service provider websites, although locating this information can be challenging. In Finland, the General Transit Feed Specification (GTFS) is a prevalent method for presenting travel information and showcasing trip details, routes, and stop information in a machine-readable format [30]. However, GTFS-format data primarily represents singular aspects such as wheelchair-accessible locations, vehicles, paths, or stops and does not address the breadth of accessibility difficulties.

TABLE III. USED DATA SOURCES AND FORMATS

Data sources for accessibility information present		
Data source name	***File format***	***Accessibility***
GTFS	Data presented in CSV files which are collected in a ZIP file.	wheelchair accessible, wheelchair boarding
NAP	Data presented in GeoJSON. It utilizes the JSON file format for representing geographical data structures.	boarding-assistance assistance-dog-space, accessible vehicle, low-floor, step-free-access, suitable-for-wheelchairs, suitable-for-stretchers
NeTEx	Data is presented in XML file format which is a markup language for organizing and storing data in a structured format.	Wheelchair access, Step free access, Escalator free access, Lift free access, Audible signs available, Visual signs available
VR	Website	Written information
Matkahuolto	Website	Written information
Opas.matka.fi	Website	Written information

Information must be presented in multiple ways to cater to diverse needs. This necessitates employing various formats and methods to ensure information is accessible digitally and that physical environment accessibility information is conveyed throughout the entire travel chain. The varied data formats are depicted in Table III. These data sources were analyzed to reveal potential accessibility information within the data sources. The collection of this data was guided by the requirements identified from the interviews, which focused on gathering preliminary information and specifics about the trip.

To ensure comprehensive accessibility, it is crucial to address the diverse needs of users by presenting information in varied formats and using multiple methods. This strategy ensures that accessibility information is available in digital formats and is effectively communicated throughout the entire travel process, thereby enhancing the overall user experience. The analysis of different data formats, as detailed in Table III, facilitates a thorough examination of potential accessibility information within the data sources.

Furthermore, the data collected from these data sources was specifically tailored to meet the requirements identified during the interviews, which focused on preliminary information and trip specifics. Incorporating insights from these interviews, the study seeks to improve the understanding of accessibility challenges and opportunities within the context of various interfaces and data structures. This comprehensive approach is vital for developing inclusive and user-friendly solutions that meet a wide range of accessibility needs in transportation and travel services.

The data formats present accessibility information at a basic level. For example, the common GTFS format categorizes accessibility in three stages with values ranging from 0 to 2, indicating the level of accessibility for different stages in the travel nodes. These values represent the stage of accessibility as follows for stops:

- 0 = No accessibility information
- 1 = Some vehicles at this stop can be boarded by a rider in a wheelchair.
- 2 = Wheelchair boarding is not possible at this stop.

For trips, the information is as follows:

- 0 = No accessibility information for the trip.
- 1 = Vehicle being used on this trip can accommodate at least one rider in a wheelchair.
- 2 = No riders in wheelchairs can be accommodated on this trip.

In Riihimäki's public transportation system, GTFS files indicate an accessibility level of 0, which means there is no accessibility information available for any trips or stops in the city of Riihimäki, which is a clear deficiency according to the information mentioned earlier about the obligation to provide essential accessibility information by the ministry [6]. The lack of accessibility information results in the inability to search for wheelchair-friendly or accessible options for trips in Riihimäki, posing challenges for finding suitable public transportation options for PwD.

Travel chain accessibility information is distributed through various sources, and operators collect this data for the NAP. The instructional materials provided by the NAP are intricate, and the guidelines for submitting information suggest that accessibility details are to be filled in multiple fields. However, the instructions lack clarity on how and where the information should be entered.

During the interviews with travel service providers, it became evident that they possessed a wealth of information. Nevertheless, there is a lack of a standardized method for presenting this information on their websites and for submitting accessibility data to the NAP. Improved guidelines are needed to ensure that the information is effectively filled in, benefiting both authorities and passengers.

During the data collection process in this study, there was a need to map various data sources and explore methods for presenting accessibility information and data formats. Among the materials investigated, the Network Timetable Exchange (NeTEx) format emerged as particularly noteworthy for its ability to offer a more comprehensive range of accessibility information compared to GTFS. NeTEx can organize collected data in a manner that allows for more detailed accessibility information, including the presentation of information at different stages within the travel chain. This format provides an opportunity to conduct an accessibility assessment, highlighting the accessibility characteristics of various entities utilized by passengers and outlining limitations in six distinct accessibility needs [30]:

- Wheelchair Access: indicates whether the service or location is accessible for individuals using wheelchairs.
- Step Free Access: indicates whether some steps or obstacles could hinder access for passengers.
- Escalator Free Access: indicates if escalators are available for passenger use.
- Lift Free Access: indicates the presence of lifts for vertical transportation.
- Audible Signs Available: indicates whether audible signs or announcements are provided for passengers.
- Visual Signs Available: indicates whether visual signs or information are provided for passengers.

The comparative analysis of NeTEx and GTFS models reveals significant differences in their approaches to accessibility data management in public transportation systems. While GTFS, widely used in Finland, employs a simplified three-tier classification system (0-2) primarily focused on wheelchair accessibility, NeTEx offers a more comprehensive and sophisticated framework through its XML-based structure. Unlike GTFS's limited scope, NeTEx incorporates six distinct accessibility parameters: wheelchair access, step-free access, escalator-free access, lift-free access, audible signs, and visual signs availability. This expanded framework enables more detailed accessibility assessments and better supports diverse user needs throughout the entire travel chain. The structured data organization in NeTEx facilitates improved data interoperability and machine readability, allowing for more nuanced representation of accessibility features at various stages of the journey. This comprehensive approach makes NeTEx particularly valuable for developing inclusive transportation systems that can effectively address the diverse accessibility requirements of all users, surpassing the basic categorization limitations inherent in the GTFS model.

C. Enhancing Travel Accessibility through MaaS Integration

MaaS integration presents a valuable solution for achieving high levels of accessibility and inclusivity in travel. Our research demonstrates that MaaS significantly aids in the information search process, enabling users, including PwDs, to find suitable travel chains. Through the diverse services and integration possibilities offered by MaaS, it becomes feasible to create personalized user profiles and purchase tickets that effectively meet the needs of PwDs, ensuring their requirements are adequately addressed within the transport system.

To illustrate the current landscape of MaaS applications and their accessibility features, we conducted an exploration of services commonly used by PwDs. Table IV presents our findings, demonstrating the overall accessibility, MaaS integration level, and specific features provided by each service.

To assess the MaaS integration level presented in Table IV, a three-tier metric was created. This metric allows for the categorization of service integration levels and the evaluation of possibilities to find suitable travel chain options. The MaaS integration levels are defined as follows:

1. Low Integration: Services at this level have minimal connection to the MaaS ecosystem. While they may provide valuable assistance to PwDs, they operate largely independently of other transportation services. These services might offer specific functionalities like navigation aids or accessibility information but typically lack integration with booking systems or other transport modes.
2. Medium Integration: Services with medium integration have established some connections to the MaaS ecosystem. They may offer features that link to other transportation services or provide limited multi-modal journey planning. However, they might lack full integration in areas such as unified payment systems or comprehensive real-time data across all available transport options.
3. High Integration: Highly integrated services are deeply connected to the MaaS ecosystem. They typically offer comprehensive journey planning across multiple modes of transport, real-time updates, integrated booking and payment systems, and seamless transitions between different transportation providers. These services often act as one-stop-shops for planning, booking, and managing entire journeys, regardless of the transport modes involved.

TABLE IV. MAAS APPLICATIONS AND THEIR ACCESSIBILITY FEATURES

Services Used by PwDs and MaaS Access				
Application	***Type of Service***	***Features for PwDs***	***MaaS Integration Level***	***Accessibility Level***
VR Matkalla	Travel Planner	Travel chain building, User profiling, Limited: Combined agreement, Tickets	High	High
Reitit ja liput (Trips & Tickets)	Travel Planner	Travel chain building, Address-to-address routing, Limited: First/last mile solutions, Tickets	Medium	Medium
BlindSquare	Accessible Place Simulation and Navigation Aid	Place simulation, Indoor navigation, Outdoor navigation, Limited: on-demand sound beacons, Nearby transport info, Platform guidance, Tickets	Medium	High

The accessibility metrics presented in Table IV are formulated from a combination of PwD user experiences, service provider accessibility policies, and compliance with Web Content Accessibility Guidelines (WCAG) standards, as required by the Finnish government [31][32]. We evaluated the applications' multi-format usability, including screen reader compatibility, adjustable text sizes, and navigation simplicity. The accessibility levels are defined as follows:

1. Low Accessibility: Services at this level offer basic functionality but have limited features specifically designed for PwDs. They may have some accessibility considerations but fall short in providing comprehensive support for various types of disabilities. These services might be usable by some PwDs but often require significant effort or additional assistance.
2. Medium Accessibility: Services with medium accessibility have made notable efforts to accommodate PwDs. They include several features designed to assist users with different disabilities, such as screen reader compatibility, adjustable text sizes, or simple navigation for mobility-impaired users. While these services are generally usable by many PwDs, they may still have some limitations or areas for improvement.
3. High Accessibility: Highly accessible services demonstrate exceptional consideration for PwDs across various disability types. They typically offer a wide range of accessibility features, such as full screen reader support, voice control, customizable interfaces, and detailed accessibility information for physical locations. These services are designed with universal access in mind and can be used independently by most PwDs without significant barriers.

D. MaaS and NAP Integration

Our research uncovered significant gaps in how MaaS platforms incorporate data from NAPs. The structure of NAPs typically consists of a Catalog, which contains Metadata describing the available datasets, and the actual Datasets themselves. In the realm of public transportation, these datasets are particularly rich and diverse, encompassing static information like routes and schedules, as well as dynamic data such as real-time vehicle locations and service disruptions [33].

Upon examining the detailed metadata from the NAP covering the City of Riihimäki area, we identified notable gaps. These findings highlight the need for NAP information, particularly in Riihimäki, to be at a level that enables effective MaaS service integration. When NAPs function as centralized platforms for transport-related data, they allow MaaS providers to access real-time information easily, thereby enhancing the quality and reliability of services offered to users [34].

However, there is a notable lack of standardization in data exchanges and real-time data delivery from transport systems, which hinders large-scale system integration. Addressing these challenges is crucial for realizing the full potential of MaaS and improving accessibility for all users, especially PwDs.

The integration of MaaS with NAPs significantly improves the user experience by facilitating seamless journey planning, booking, and payment across various modes of transport. Users benefit from a more convenient and efficient travel experience, leading to increased satisfaction and usage. By accessing comprehensive data, MaaS providers can optimize routes, reduce travel times, and improve service efficiency, resulting in cost savings for both providers and users.

Improved accessibility is another significant benefit of this integration. Integrated systems can offer tailored solutions for different user groups through profiling, including PwDs, by providing more accessible and inclusive transport options. The purpose of integrating MaaS with NAPs is to serve as a centralized data hub. NAPs collect, store, and distribute transport data, supporting the efficient functioning of MaaS by ensuring that all stakeholders have access to consistent and up-to-date information.

The integration of MaaS and NAPs holds great promise for enhancing travel accessibility and inclusivity. By addressing current gaps and standardization issues, we can create a more seamless, efficient, and accessible transportation ecosystem that benefits all users, particularly those with disabilities.

E. Implementation Framework for Accessible MaaS Integration

The implementation of accessible MaaS requires a comprehensive architectural framework that addresses both technical integration and accessibility requirements. This framework, illustrated in Figure 1, establishes a hierarchical structure that enables seamless information flow while ensuring accessibility remains a core consideration throughout the system.

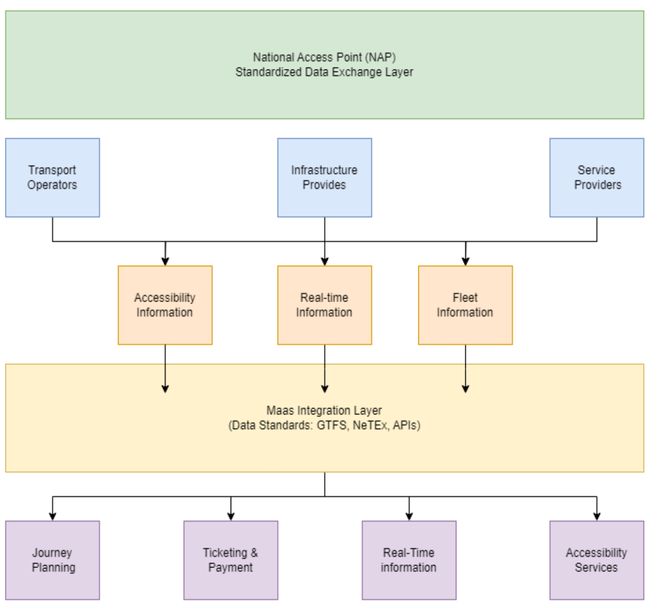

Figure 1. Architectural impelementation plan of MaaS integration service.

At the highest level, as shown in the topmost layer of Figure 1, NAP serves as the cornerstone of the architecture, providing a standardized data exchange layer that facilitates cross-border interoperability and consistent information sharing. This overarching framework ensures that accessibility information maintains its integrity across different systems and jurisdictions, supporting the broader goal of inclusive mobility solutions.

The architecture's data source layer (depicted in the second tier of Figure 1) concludes various stakeholders, including transport operators, infrastructure providers, and specialized service providers, each contributing essential information to the ecosystem. Transport operators provide crucial details about vehicle accessibility features and operational schedules, while infrastructure providers maintain comprehensive information about physical facilities and their accessibility characteristics. Service providers complement these primary data sources by offering specialized accessibility information and assistance services, creating a robust foundation for inclusive mobility services.

Central to the architecture, as illustrated in Figure 1's middle layer, is the MaaS Integration Layer, which employs established standards such as GTFS and NeTEx, alongside modern APIs (Application Programming Interface), to ensure seamless data interchange. This integration layer serves as a crucial mediator, transforming diverse data formats into standardized structures that support accessibility service delivery. The implementation of this layer requires careful consideration of data models that can sufficiently represent accessibility features while maintaining compatibility with existing transportation data standards.

The service layer, shown at the bottom of Figure 1, represents the connection of the integrated data and services, manifesting in four primary functional areas: journey planning, ticketing and payment systems, real-time information services, and specialized accessibility services. Journey planning incorporates accessibility considerations directly into route optimization algorithms, ensuring that suggested routes align with users' accessibility requirements. The ticketing and payment systems are designed with universal access principles, while real-time information services provide crucial updates about service disruptions and accessibility status changes. Dedicated accessibility services within this layer coordinate specialized assistance and support, ensuring that users with specific needs receive appropriate accommodation throughout their journeys.

The vertical integration emphasis shown by the connecting arrows in Figure 1 illustrates the continuous flow of information from data sources through to end-user services, ensuring that accessibility considerations flow in every aspect of the system. This comprehensive approach supports the development of truly inclusive mobility solutions that can adapt to diverse user needs while maintaining high standards of service delivery.

This implementation framework represents a significant step forward in the development of accessible transportation systems, providing a structured approach to integrating accessibility considerations throughout the MaaS ecosystem. Through careful attention to standards, stakeholder needs, and user requirements, the framework supports the progressive realization of truly inclusive mobility solutions that serve the diverse needs of all transportation system users.

V. Discussion

The analysis of accessibility information in various data sources reveals several aspects that require further clarification and definition. The challenges faced by PwDs in utilizing accessibility information can be categorized into six major themes for improvement, addressing information gaps in the preliminary phase, during trips, throughout the travel chain, and in MaaS possibilities:

- Improving accessibility information: providing clear and comprehensive details about the accessibility of different modes of transportation, such as stair heights, ramp availability, and the location of assistance points, is essential for helping passengers with disabilities plan their journeys effectively.
- Enhancing assistance services: it is crucial to ensure that assistance services are easily accessible and that the ordering process is clear and seamless. Additionally, having assistants available at critical locations like stations and trains is important.
- Utilizing technological solutions: offering practical mobile applications to passengers that provide real-time information on transportation accessibility, schedules, and ticket reservations can significantly enhance independent travel for passengers.
- Collaboration among stakeholders: close collaboration among public transportation operators, tourism services, and associations for PwDs is necessary to promote accessible travel. Through collaboration, better solutions and services can be developed for passengers with disabilities.
- Improving guidance accessibility: ensuring that accessibility information is available in various formats, such as tactile pathways, easy-to-read maps, and providing Braille, and audio guidance. It is crucial to ensure all passengers can access the information they need.
- Customer services and location accessibility: ensuring the availability of customer service locations, providing location-based information about the traveling center building, and determining the availability and specifications of accessible routes and services, e.g., toilet spaces are important considerations for enhancing accessibility for all individuals.

The concept of an accessible travel chain is a matter of social equality and justice. Barrier-free travel chains ensure that all people, including people with reduced mobility, such as people in wheelchairs, visually impaired, or hearing-impaired, can travel on public transport as independently as possible and without barriers. A barrier-free travel chain is smooth, safe, and effortless for everyone. For example, physically barrier-free stops, stations, elevators, and multi-sensory signs, make traveling from one place to another easier and smoother. Raised platforms and low-floor train carriages reduce the risk of tipping over and enable easy access to and from the train. The ease and comfort of traveling improve everyone's travel experience.

In relation to MaaS services, e.g., within digital journey planners and route guides, more comprehensive data access and more advanced combination services as well as advanced user profiling and user sensitivity choices could in the future help in the rerouting of the travel chain when facing unexpected challenges during the journey. During the research, user profiling options were so far modest, especially for the passenger himself.

The evolving EU regulations and standardizations significantly impact the development and integration of MaaS solutions into travel chains. These updates influence how PwDs utilize technological solutions, including combination services and MaaS features. For instance, services like *VR Matkalla* facilitate the creation of travel chains by combining agreements and offering routes and tickets in collaboration with *Matkahuolto*. They address challenges in demand-responsive transportation, particularly in the first and last 15 minutes of travel, providing door-to-door solutions. Similarly, BlindSquare assists visually impaired users by simulating unfamiliar places and providing information about nearby public transport services and platforms, benefiting PwDs with digital skills.

In the realm of information sharing, GTFS and NeTEx are the most common formats for presenting metadata from systems and various nodes. However, the level of detail in accessibility information provided by different operators and service providers varies, creating challenges due to the lack of clear guidelines on reporting physical nodes.

The adoption of similar standards for collecting transportation, travel chain, and infrastructure information across European countries enhances the accessibility of these chains and facilitates cross-border travel. This harmonization, supported by NAPs, opens numerous possibilities to improve accessibility information for all travelers, including PwDs, catering to diverse user needs. The integration and development of NAPs, along with perspectives on NeTEx and European development, play a crucial role in ensuring that data integration and accessibility are prioritized in the evolving landscape of MaaS solutions.

It is important to note that for some services it has been possible to create only a minimal connection to the platform built with the MaaS concept, even though they could offer, e.g., valuable navigation assistance or accessibility information. These thinly connected services do not integrate with the ticket reservation systems of other modes of transport, but only provide a link to another service. The integration possibilities of these services are limited by overly complex agreements and conflicting business models between the parties.

By these means the development of accessible MaaS solutions requires a multifaceted approach, addressing technological, infrastructural, and collaborative challenges. When focusing on these key areas, there is possibilities to go towards creating a more inclusive and efficient transportation system that truly serves the needs of all users, regardless of their abilities.

VI. CONCLUSION AND FUTURE WORK

The landscape of MaaS in Finland is rapidly evolving, bringing both opportunities and challenges. A comprehensive analysis of accessibility information needs, compared with existing databases and data sources, reveals significant areas for improvement in public transport and travel chain development. This insight is crucial for enhancing the travel experience for all users, particularly those with diverse needs.

Legal frameworks and ethical guidelines emphasize the importance of equal treatment for all passengers, underscoring the need to accommodate various individual requirements in the development and execution of public transportation systems. However, the increasing reliance on digital platforms for mobility information and service purchases presents new challenges. As personal services at stations and service points diminish, ensuring universal access to mobility services becomes more complex. This shift particularly affects individuals with limited digital skills, those requiring assistive technologies, and people who face challenges in obtaining digital travel information.

The usability of MaaS applications is a critical concern. Many users face a steep learning curve due to the lack of clear, user-friendly instructions. They often struggle to navigate complex interfaces, understand various transport options, and manage intricate booking and payment systems. Most operators expect users to learn through self-exploration, which can be daunting, especially for those less familiar with digital technologies. While efforts to improve digital information flows are essential, it's equally important not to neglect the development of traditional customer service aspects.

In this complex ecosystem, clearly defining areas of responsibility among various stakeholders is crucial for seamless operation. Key players in Finland's MaaS landscape include cities, transport operators, service providers, and municipalities. Each entity has distinct roles, yet their responsibilities often overlap, necessitating clear delineation and cooperation. Cities, for instance, play a pivotal role in MaaS implementation, being responsible for local transportation infrastructure, urban planning, and often operating or contracting local public transport services. They also set local transportation policies that significantly impact MaaS operations.

Collaboration among transportation service providers, cities, and other stakeholders is essential for developing solutions that facilitate effective communication, planning, and information gathering. This cooperation is crucial for meeting EU requirements for data collection from transport nodes. By leveraging up-to-date data, service providers can enhance their ability to offer suitable travel chains for everyone, PwDs.

The integration of data into centralized platforms, such as NAPs, can significantly enhance MaaS development. This integration supports the use of MaaS across multiple modes of transportation, promoting accessibility and compliance with standardization and legislation. It also facilitates the creation of seamless travel chains, improving the overall travel experience for all users.

As we move forward, it's crucial to balance technological advancements with inclusive perspective and Universal Design Principles. While digital solutions offer numerous benefits, they must be developed with consideration for all user groups. This includes providing comprehensive guidance on how to use MaaS applications effectively and ensuring that digital interfaces are intuitive and accessible to users with varying levels of technological proficiency.

The development of MaaS in Finland presents a multifaceted challenge that requires a holistic approach. By addressing accessibility needs, improving usability, fostering stakeholder collaboration, and integrating data effectively, Finland can create a more inclusive, efficient, and user-friendly mobility ecosystem. This approach not only enhances the travel experience for all but also sets a standard for sustainable and accessible urban mobility solutions worldwide.

Declaration of Conflicting Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgement

The authors declare financial support was received for the research, authorship, and/or publication of this article from the Regional Council of Häme, from the funding "Support for Sustainable Growth and Vitality of Regions".

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Teacher Beliefs about Wearables and Gaming

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***Abstract*— This study examines practicing teachers' thinking on wearable gaming for educational purposes. Specifically, it explores teachers' envisioned use of wearable gaming and their perceptions about the pros, cons, and challenges of wearable gaming in the context of education. Adopting a case study approach, data were collected from 31 teachers enrolled in a graduate course. The results showed that teachers considered conveniences, flexibility, social emotional development, etc. as pros, while over reliance on technology, hazards, and inequality, etc. were cons. Interestingly, several other aspects were articulated by teachers as both pros and cons. Specific ways to apply wearable gaming for educational purposes were also discussed.**

Keywords-component; wearable gaming; game-based learning; teacher perceptions; wearable design.

I. INTRODUCTION

This paper builds upon the original conference paper with substantial additions and deeper analysis to enhance the context, methodology, and findings of the research [1]. These extensions provide a more comprehensive and rigorous examination of the study.

The power of digital game-based learning is now widely accepted as reflected, for example, in well recognized publications including the Federation of American Scientists' (FAS) report [2] in which games are considered as a powerful tool with great educational potentials [3]. Various studies have demonstrated that games can enhance learners' conceptual understanding [4], motivate students [5], and positively influence players' attitudes [6]. On the other hand, wearable technology has increasingly attracted attention from researchers and developers for its power to enhance student learning anywhere and anytime.

Despite the growing interest and increased number of studies in the field, how to best design wearable technology for learning in general, and how wearable technology on game-based learning (GBL) can be optimally used remain underexplored [7]. The adaptation of wearable game-based learning in classrooms is scarce due to various reasons. For example, teachers often found it challenging to connect wearable games with existing curriculum [8]. The technical skills required to use wearable gaming can be another roadblock for teachers [9]. Using wearable tools can be too complicated for teachers [8].

This study, therefore, aims to bridge this gap by examining teachers' thinking and envisioned use of wearable gaming for educational purposes. Understanding what teachers concern the most as they consider wearable games for instructional purposes can help us not only better design instructional and training practices for teacher education, but also identify effective approaches for educational wearable game design that are aligned with existing curriculum and meet the needs of the teachers and their students.

II. RELATED LITERATURE

Wearable technologies, referred to digital devices that can be easily attached to our bodies as accessories or clothing, are gaining increased attention from educators, researchers and designers. Small and affordable wearables such as watches, glasses, rings, and other accessories allow users to monitor several biometric factors, control their smartphone apps via voice and gesture, play games unique to the technology, and much more. It has been argued that wearable technologies hold substantial educational potential for their ability to enhance interaction, collaboration, and immersive learning [10].

A. *Wearables and Games*

Still in their infancy, wearables that were initially planned only as medical devices have the potential to provide solutions beyond the healthcare and personal sectors [11]. Gains in data transfer and storage, energy efficiency, and connectivity as well as the capability to augment reality (AR) or provide virtual reality experience (VR) in off-the-shelf wearables have made them attractive for educational integration [12]. Additionally, wearables possess three qualities that make them compelling: wearables can collect data from the wearer on an ongoing basis, the wearable can have a direct relation to the wearer's public appearance, and wearables can monitor bodily systems to improve the wearer's quality of life [13].

User adoption of wearables can be influenced by factors such as age, trust of technology, data protection concerns, technology-related health concerns, technical skills, and the wearable's ability to interoperate with other technology-based infrastructure [11]. Additionally, there exists concern over the sustained integration of wearables, as individuals who adopt wearables – specifically fitness trackers – tend to abandon them within months after first use [14]. Designers have attempted to combat this phenomenon by adding features that some users view as gimmicks versus valuable tools [15].

A survey study [16] of 70 participants examined public perception of wearables for every day, moment-to-moment learning opportunities were evaluated. Using nine scenarios based on task-oriented activities- that include assistance needs, health monitoring, and location-based use- they found there was a positive inclination to use wearables as a learning tool. Additionally, the survey seemed to perceive wearables to already support some form of learning with their current set of abilities. As an example, tracking one's heart rate was viewed as learning about oneself. Of the many types of wearables available, the study found smartwatches and smart glasses to be the most chosen devices amongst respondents for use in these fictional, everyday scenarios.

Video games or gamified experiences can present multidimensional combinations of the wearer's sensations [17][18]. Tied to wearable technology, gamification has the potential to utilize game design elements in non-game contexts with the anticipated outcome of affecting the wearer's behavior [19]. In a literature review study by Windasari and Lin [14], ten empirical studies were examined to identify ways to sustain the use of wearables with a focus on interactivity levels and the inclusion of game-design elements. They reported that the higher the level of activities built into the wearable, the higher the continued use. This is to say that wearables that collected data alone were not as useful to a user as those that collect data and share it with larger, integrated systems. Instead, implementing game mechanics, especially those that link to social elements, such as competition and collaboration, leads to a higher intention of use.

B. *K-12 Education and Wearables*

Wearable technology can afford educational experiences that are intrinsically motivating and relevant to school aged children [20]. Available off the shelf, they require minimal modifications to be incorporated into a curriculum [21] but may necessitate the development of additional hardware/software supports to be meaningful. Evidence also suggests that wearables can achieve certain positive outcomes in students with learning disorders and disabilities [22].

In a study [23], 808 elementary students were given an opportunity to engage with e-textiles powered by the LilyPad Arduino. The results showed that by making the wearables customizable and visible, students were more apt to use, dress, and show off their wearables to family and friends. Created through a combination of electronics and crafting materials that include a microcontroller, sensors, actuators, and conductive thread, this STEM activity allowed students the opportunity to engage with a personalized challenge through a relevant, authentic learning process. They concluded that wearable textiles that combine computer science with aesthetics can work as cognitive tools for problem solving, programming, design, and other STEM content.

An earlier work [24] compared outcomes such as student engagement, student motivation, and student excitement using the same pedagogical strategy on two distinct technological platforms: Palm hand-held devices and smart badges in two high schools and one middle school to play games based on complex systems: 188 high school students were randomly assigned and grouped to use either the Palm handheld devices or the smart badges – dubbed thinking tags - to play a simulation built on Mendelian genetics. An additional 82 middle school students played Virus - a game that explored the spread of a disease – using either the Palm or thinking tags. The results reported that both versions of the simulation were exciting and motivating, with students remaining engaged through interaction, investigation, collaboration, and testing. With little difference in the collected data and how the activities unfolded using the Palm or the think tags, the researchers concluded that using the inexpensive think tag technology in simulations holds great promise for integrating technology in authentic, collaborative learning opportunities that students will find engaging and motivating.

Ko and colleagues [25] adopted an experimental approach, connecting gaming experience with somatic exercises. A somatic game called We Wave was presented to children of 5-12 years old. Using a Wii Balance Board to map movement to music, they discovered that most children were able to enter in proper kinesthetic interactions with a cooperative player. In 2014, We Wave was adapted to the sensorimotor facility of autistic children, where it was found that the environment can help with anxiety through a blend of sounds being in time with body movement. Once relaxed, these players were involved in non-verbal interaction and shared emotions with cooperative players. In their follow up project, VR headsets were added with the intention to create an in-game body experience coupled with binaural spatialization sound synthesis for sensorimotor.

In a randomized clinical trial by Voss et al. [26], 71 school-aged children (six to 12 years old) with autism spectrum disorder (ASD) used Superpower Glass (SG), an artificial intelligence-driven intervention deployed via smart glasses and a smartphone app, to teach recognition and relevance of emotion. Amongst the children, 40 were randomly selected to be treated with the SG and applied behavioral analysis (ABA) therapy while 31 used ABA therapy alone as the control group. Families were asked to conduct 20-minute sessions at home four times a week for six weeks. Concluding the treatment, the children who used SG and their associated games showed significant improvements on the Vineland Adaptive Behavior Scale socialization subscale when compared to the control group. That is, using wearable technology to teach the recognition and relevance of emotion better improved student socialization as compared to receiving regular therapy.

In general, this body of literature suggests that accessible wearables and those that integrate gamified opportunities can produce positive learning outcomes for K-12 students. By providing relevant and engaging activities that increase student motivation, wearables allow for authentic problem solving and permit collaborative learning opportunities. Furthermore, these studies show encouraging support for wearables and gaming support for students with disabilities in the classroom and at home.

C. Higher Education and Wearables

In the higher education setting, wearables can be used beyond the intrinsically motivating use of activity tracking, badging [27], receiving notifications, social communication [28], gaming, and recording features [20]. In an earlier study [29], students were asked to wear glasses during 15 standard medical simulation sessions to track their performance, including eye movement. The results included detailed information about each participant's practice style, allowing for personalized feedback and teachable moments.

Another study [30] utilized a head-mounted AR display worn by a lecturer and the 11 students to investigate the bidirectional communication of teacher-students. The results showed that using AR could improve student interaction and communication with the teacher and enhance engagement. Researchers found that feedback from students was more direct, that there was satisfaction in receiving visual cues regarding student affirmation of learning concepts, and that using AR goggles allowed the lecturer access to notes at all times while speaking.

Little research exists highlighting wearable technology and gaming being utilized in higher education. The two highlighted studies show evidence that wearables promote individualized learning opportunities, personalized and contextualized feedback, and opportunities for students' inquiry.

D. Higher Education and Wearables

Research exploring the interplay of wearable technology and teacher beliefs has gained little attention. In a study [31] of physical education (PE) teachers, researchers analyzed qualitative data focusing on teacher perceptions of incorporating wearable technologies in their practice. Data was collected from interviews of 26 teachers in the UK. Their results showed that teachers recognized the benefits of wearable tools in schools in helping with motivating, goal setting that would lead to increased physical activities. They viewed wearable tools designed for schools as acceptable. Though limited, current investigations suggested that the teacher's attitudes towards innovation determines the overall quality of integration [32].

In an initial iterative study [33] of 16 K-12 math teachers, AR smart glasses were used to support a personalized learning classroom. The system used real-time detectors found in advanced learning technologies (ALT) to simulate a learning environment that would allow the wearer to evaluate relationships with student learning gains. Teachers reported that they felt wearing smart glasses allowed them to more quickly respond to key events in the room. Interpretations of teachers' responses suggested that certain student-related information should be made simplistic, with related and more sensitive elements available on demand. As an example, viewing indicators of current student activity states would be more helpful if their pervious activity state were known – such as a student in a "not working" state due to being in a "struggling" state moments earlier. Teachers also suggested that if students were provided with a way to request help via the ALT, they would be more apt to ask for assistance.

Many review studies showed that the majority of research related to smart wearable were conducted in areas like medicine [34], sports or physical activity [35][36][37], neuroscience [38] and work environments [39]. In education, Schroeder and colleagues [40] conducted a scoping review of wrist-worn wearables (WW). Their analysis of 46 empirical studies indicated that a similar proportion of the studies focused on k-12 students and adult learners. While a wide range of subjects were explored, there is a lack of work focusing on teacher training and the use of such tools.

E. Summation

In sum, although there is research available on wearables in education, most tend to focus on awareness, features, level of comfort, and accessibility. Less attention pays to wearables and gaming in practical, K-16 classrooms. Of those that exist, most focus on student observation, interviews, and results with almost no perspective from an educator. In addition, few, if any, studies exist in the way of design research that might provide in-depth information about the optimal features of wearables and gaming [41] for educational purposes. This study thus attempts to bridge the gap by examining teacher perceptions related to wearable gaming.

III. Research Questions

This study explored practicing teachers' thinking and envisioned use of wearable gaming for educational purposes. Specifically, the following research questions guide the research:

1. What are teachers envisioning of using wearable gaming for educational purposes?
2. What do teachers believe about wearable gaming in terms of pros, cons, and challenges?

IV. Methods

This study was a case study framed in a qualitative, naturalistic research perspective [42]. Aiming to capture teachers' thinking, the focus was on investigating teachers' beliefs about wearable gaming and their envisioned educational use of wearable gaming. Complying with the case study design, this work used a range of data collection approaches to gather detailed information over extended time [43].

A. Participants and data sources

The participants were graduate students enrolled in a graduate course involving online learning. A total of 31 students participated, which constituted the sample of this study. The course was aimed at providing students with a foundational understanding of online education.

A majority of them were practicing or formal teachers in k-16 educational institutions with about 20% of them were active or previously worked as trainers in different organizations or businesses. These 31 participants (about

15% males) were referred to as teachers and pseudonyms were used in this paper. This study was part of a larger research project focused on teacher digital game design experiences. The initial data collection included class observations, assignments completed by teachers, instructor's reflective journal and learners' feedback after class. Other data sources were the teacher created digital artifacts. This paper focused on participants' reflections, although other data provided information for the context of the study and triangulation of the results.

V. Analysis

A five-stage thematic analysis [43] was adopted for data analysis. First, open coding of the data was conducted where three researchers independently preliminarily identify the themes. Secondly, these initial codes were then compared, discussed and continued to be revised during the interaction with data until mutually agreed themes were developed. Third, the initial list of codes was re-examined, and the codes pertaining to the educator perceptions, as described in the relevant literature, were isolated. Fourth, data were grouped under different codes, allowing researchers to identify patterns and themes emerging. Lastly, through repeated scrutiny, the original contextualized descriptive codes were refined to answer the research questions. The different themes were interpreted within a broader social context. Various strategies were used to ensure reliability and accuracy. For example, different data sets were analyzed, including teacher reflections, and researchers' field diaries to triangulate the results. Also, three researchers independently analyzed data. Additionally, attention was paid to extreme cases, especially to negative evidence [43].

VI. Results

A. *Teacher beliefs*

The first research question focused on teacher beliefs about wearable gaming in terms of benefits and drawbacks.
Benefits described by the teachers included: conveniences, flexibility, "[wearable] provide people with convenient, on the go solutions to their everyday dilemmas." (ST). Many argued that wearable gaming would allow highly personalized learning to meet diverse learner needs. Helping with social emotional development was an advantage cited by many teachers. Some teachers, initially wary of wearable technology for various reasons like excessive screentime and potential distractions, later discovered potential benefits of wearable gaming on students' social-emotional development. LT's following comment exemplified this:

- So my first thought was, give the kids a break. We are inundated with technology as it is...But as I thought of my students with specific needs during stressful situations, it dawned on me how successful a wearable device would be vs. a timer or adult reminder. It would build personal capacity, independence and self-awareness way more than an adult reminder or cue would.

The teachers also identified a range of cons and challenges including becoming overly dependent on technology, the possibility of hazards, and inequality. The inequality-related challenges could be brought by a multitude of factors ranging from knowledge or language barriers to cost-associated issues. Students from with limited English proficiency or exposure to the technology might be hindered from effectively interacting with the systems. Students from low-income families, schools located in rural areas or under-resourced communities might get restricted access to or maintain wearable technologies due to their financial limitations. Since wearable technologies were attached to our bodies, potential risks, such as radiation or electric shock, or side effects like dizziness, existed. The following comments provided a nice summary:

- "In terms of cons, some include gradual complete reliance on technology, potential hazards and costs. Potential challenges include inability of some populations to navigate systems due to lack of technological knowledge or language barriers, as well as cost challenges related to obtaining and maintaining the wearable over time." (ST).

An interesting observation was that several themes were identified both as positive and negative. The first example was the health-related topic. From the positive side, teachers articulated how wearable gaming could be used for real time health monitoring, thus promoting healthy behaviors and encouraging a more active lifestyle. At the same time, some teachers also considered wearables as a con due to concerns about risks associated with them. For example, some cautioned that wearable gaming might cause "hypervigilance of targeted behaviors" (EF). Additional con included the unknown impact on health from using wearable gaming since "health effects of wearables are unclear" (TB). The engagement value was the second theme that teachers considered as both beneficial and detrimental. On the one hand, teachers believed wearable gaming would attract students' attention, thus leading to effective learning. On the other hand, concerns were raised about how wearable gaming "could be a distraction" (CP).

The concept of convenience and accessibility was a third topic discussed both as a pro and a con. The teachers repeatedly stated that a benefit of wearable gaming was "being able to be worn provides a sense of convenience" (SM). At the same time, several participants deliberated that a con of wearable gaming was students could suffer from too much exposed to technology, as exemplified by SM: "some parents may not want their children to be exposed to technology consistently."

The last theme that was taken up as both positive and negative related to equity. Wearable gaming was perceived as a tool that could level the playing field because it could allow anyone to access it any time and any place. In contrast, it might create inequality due to various factors such as cost, visually impaired users, social divide, etc.

B. Teacher envisioned use

How did teachers envision wearable gaming to be used for educational purposes? A high number of teachers discussed how they foresaw the use of wearable gaming in helping with daily life skill and functioning. Diverse ideas, ranging from calendar to alarm-type programs, to behavior reminders, were shared as meaningful application of wearable gaming.

One theme that emerged was the integration of wearable gaming with augmented and virtual reality (AR/VR). Examples included “glasses could integrate AR to run scavenger hunts. VR headset could be used for simulations” (TB), or “virtual reality for history (seeing events as they happened)” (MM).

Health related topics, including mental health, were discussed by many participants. How to use wearable gaming to encourage healthy lifestyle both in schools and other workplace settings were mentioned repeatedly.

- Reviewing logs for mood, etc. may allow users to gain insights into times of day or activities that are particularly challenging or health-promoting across their day. (EF).
- In a larger workplace setting, challenges between peers would be a great way to use [wearable gaming]. A fitness challenge between coworkers might provide opportunities for involvement in a healthy lifestyle. (SF)

A closely related theme identified related to social emotional development. The teachers articulated how wearable gaming could be a valuable tool to help students manage their emotions and improve their social-emotional wellbeing.

- I would love to see a wearable device that supports social emotional well-being by providing breathing techniques with visuals for students to follow. It could encourage who struggle with sharing their emotions to have private opportunity to work on and show those skills. (KP)
- In the context of social-emotional development, a built-in reminder to breathe or use a variety of calm down/sensory activities when heart rate increases due to stress, overstimulation, etc. tailored to specific students. (LT)

Content learning, of course, was discussed by some teachers. The teachers described various approaches to using wearables, ranging from short quiz games to teach STEM to interactive activities for developing social skills. Examples that were shared by the teachers included:

- Content-based games that are brief & fast paced (e.g., quick math games based on telling time, sight word games, etc.) (SC).
- As a math teacher, I would love to access wearable gaming for educational purposes. If the wearable gaming device allows students to track their speed and time, we could measure a multitude of different scenarios. Using this data...students could solve for equations in relation to their data tables. This type of learning activity would change the way students view algebra concepts (TK).
- In a formal setting I could see using it as a way to incorporate some games into the lesson, such as that one game where the person wears their identity on their head and other people give them clues about it to enhance their social and team building skills (SM).

Equity was another theme identified. Teachers explained how they could use wearable gaming to provide differentiated learning to help diverse learners such as those with special needs.

- In classrooms, students with attention challenges could be quietly prompted to monitor if they are on task or not. I could imagine building reward systems or a game-related component to earn points. (EF)
- Wearable gaming could be a great way to seamlessly bring differentiation into a lesson and level the playing field for all students. (SR).

Heightening social connection and collaboration to break the brick and mortal boundaries was another theme that emerged.

- Students could connect in group activities without having to physically sit next to each other. (BD)

VII. Discussion

Today’s rapid growth of technology and its variety of interconnected devices that are small and affordable gave way to a new technology market – wearable technology. Although with great potential, how to harness the power of wearable technology and gaming, especially in K-12 classrooms, remains largely missing in the current body of literature. Aiming to address this gap, this study has explored practicing teachers’ perceptions related to wearable gaming.

Several results from the analysis of data are worthy of further discussion. The most significant contribution of this study is the revelation that teachers identified some benefits of wearables, which they also perceived as drawbacks. Health related topics are the first to exhibit this ambivalent relationship. For example, teachers recognize great benefits of wearable gaming in promoting and encouraging healthy, active lifestyles. On the flip side, teachers are concerned about potential risks such as hypervigilance of targeted behaviors and unclear health effects associated with wearable gaming.

The second example of this contradictory belief relates to the engagement value of wearable gaming. Teachers view the huge benefits of wearable gaming for capturing students’ attention, thus enhancing learning, while at the same time considering it detrimental due to potential distractions. Teachers perceived that wearable gaming can increase students’ interest in learning, which aligns with the previous research [23] that students are excited to actively learn through wearable gaming.

A third example of such seemingly conflicting viewpoints is that teachers discuss the convenience of wearable gaming, while at the same time expressing concerns about excessive technology exposure. This is similar to the results of a previous study [31], which found that teachers acknowledge the potential of wearable technology in schools yet also present possible negative effects like health and safety issues. Equity is the fourth topic that elicited teacher divergent opinions. On the one hand, wearable gaming can promote equal access due to its anytime, anywhere availability. On the other hand, cost, social divide, etc. can exacerbate inequality.

In this study, teachers have shared their diverse visions for using wearable gaming, from using wearables for different subjects, to promoting collaboration. It suggests the multitude of possibilities that teachers see in using wearable gaming in their classrooms. Yet, the opposing stances shared by the teachers highlight the importance of professional development to ensure all teachers gain a thorough understanding of the pros and cons, and best practices with wearable gaming. Such deepened understanding can help align teachers' perspectives and allow them to create a more effective approach. To ensure wearable gaming is not a fad, it needs to be integrated intentionally, with teacher awareness, alignment to broader systems, and the provision of unique kinesthetic learning opportunities.

Just like any educational research, there are limitations of this work. First, this is a qualitative study with no quantitative data analyzed. Future research is recommended to include quantitative data in order to gain a broader perspective. Secondly, the study focuses on in service educators only. We suggest additional research also explore preservice teacher perspectives.

VIII. Conclusion

The gaming market is still growing with an expected value of US $545.98 billion dollars by 2028, according to the 2022 Fortune Business Insights [44]. Further, gaming is becoming more and more diversified: being played pervasively (e.g., AR games), on new platforms (e.g., VR, mobile games), being played by different groups (e.g., different age levels, both male and females, etc.) [41]. Wearable gaming undoubtedly has its advantages including but not limited to, allowing our body to be used as a controller, enabling more flexible playing and promoting social connections. Yet, wearable game-based learning has little success in education, partly due to its recent emergence. This study addresses the gap in the literature related to wearable gaming and teacher perceptions, adding valuable information to help us understand the value and design considerations of wearables in the context of wearable gaming. Practically, the results of this study are readily understandable by practitioners, which can help guide game designers, developers and educators to best design and use of wearable gaming for educational purposes.

Note: An earlier version of this paper was presented at the 16th International Conference on Mobile, Hybrid, & Online Learning (eLML2024), Barcelona, Spain.

AI tools such as Google Gemini and Grammarly were used to help generate initial ideas and offer editing assistance. The tools were used in the same way as one might employ a writing tutor.

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An Assessment of Differences in Human Depth Understanding in Cube Displays Utilizing Light-Field Displays

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***Abstract*—The proliferation of study into three-dimensional (3D) digital content affirms its popularity, not only in academics but in the business and private sectors as well. Virtual and augmented realities have been an attractive means of viewing and interacting with three-dimensional (3D) content. A Light-Field Display (LFD) allows users to experience stereoscopic images, using a similar approach to Virtual Reality but without the need for a headset. This study aims to expand upon the preliminary experiment, in which we evaluated the benefits of stereoscopic depth cues in human visual understanding through users viewing a 3D scene on a cube display. Our task scenario involves users interacting with the 3D cube display to judge the distance between objects and completing a questionnaire about the experience. For each test, using the LFD "Lume Pad" produced by Leia Inc., 3D contents were presented with and without stereoscopic depth cues. Our results show that users can judge the distance between objects with more certainty and with fewer errors with stereoscopic depth cues.**

Keywords-Light-Field Display; Fish Tank VR; 3D human perception; stereoscopic vision.

I. INTRODUCTION

Two-dimensional (2D) screens allow for almost anything imaginable to be displayed. Complicated data is transformed into graphs, charts, lists, and other visuals designed for easy accessibility. Users can see places, objects, cultures, and creatures that they have only ever heard of. However, there are limits to what can be conveyed, as a 2D screen is incapable of showing true depth because it has no real depth. This paper is an extension of our previous work, evaluating the benefits stereoscopic depth cues bring to perceived depth understanding when using a Fish Tank VR cube display [1].

Since a 2D screen has no depth, the illusion of depth must be created using depth cues. Some of these cues are stereoscopy, convergence, occlusion, relative size, height in the visual field, relative density, aerial perspective, accommodation, and motion parallax [2]. These cues are utilized to a greater or lesser extent to recreate depth on a flat surface, such as a 2D screen, and the developing technology that manipulates these cues is what 3D screens are built around.

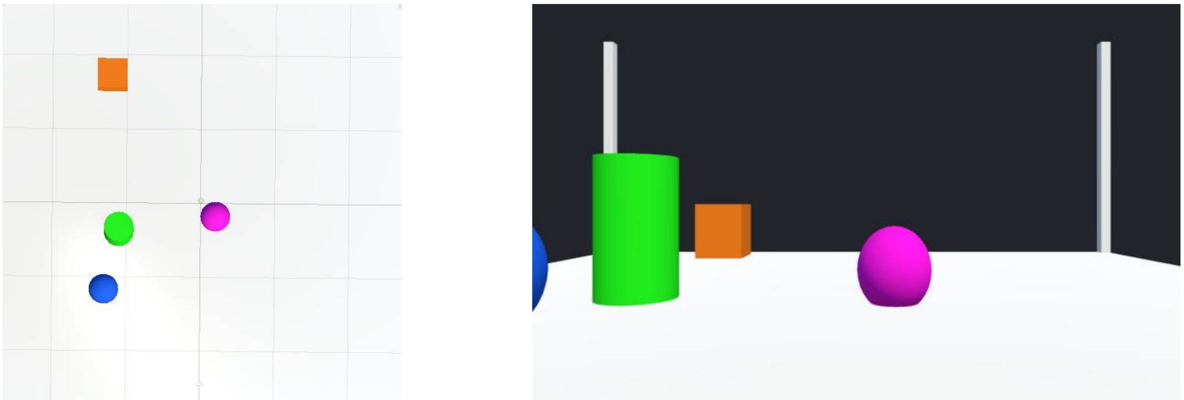
With the rise of virtual and augmented reality headsets, 3D digital content has become more commonplace. This content allows users to interact with 3D media in a fashion that was unimaginable a decade ago. A key component to these devices is that they create stereoscopic depth cues, giving the user the sensation of seeing a true 3D scene.

A lesser-known category of this type of display is handheld displays, such as smartphones and tablets. Further advancements have been made with 3D content in hand-held displays, with the vast majority of these advancements coming in the form of augmented reality applications that use the device's camera and add digital content to what the camera can see. Conversely, some handheld devices are being designed with hardware to be used primarily as AR or VR devices.

One example avenue of these hardware advancements is handheld LFDs. LFDs use curved lenses, known as lenticular lenses, to bend the images displayed behind them in such a way as to cause each of the viewer's eyes to see a different image. This creates an experience similar to VR and AR headsets but without the need for a headset. Most people have come into contact with this technology, albeit in a less technologically advanced form. Lenticular lenses placed over static images create pictures that appear to be 3D, move, or change into another image entirely. This is a popular technique used to make unique postcards and stickers. An LFD brings this technology to a digital screen. Many LFDs are very large and complicated, using multiple projectors aligned with complex lenticular lens arrays to create 3D images that can feel like someone is looking at a hologram from a science fiction movie. One such example of this is the 120-degree viewing angle LFD designed by Liu et al. [3].

Another form of 3D display is what is known as Fish Tank VR displays. These displays have a 3D shape and thus can make use of actual depth. In theory, any shape that can be created with physical objects can be made into a display, allowing for custom displays to be built specifically for individual tasks. One example is the SpheriCul [4] designed by Prima Lab. This sphere-shaped display has many different uses, such as allowing users to walk around the sphere display and see any content that is globe-shaped or to use a tracker to have the display alter its image to fit what the user should be seeing from the angle they are standing.

The purpose of this study is to improve our preliminary findings and to present the benefits to a user's understanding of perceived distance in a cube display by adding stereoscopy. To this end, three new tests were created. These tests were designed to improve upon the previous experiment and to expand upon the ideas proposed in that paper. The first test takes the lessons learned from our previous work to improve



(a) Top-Down view from Unity

(b) View from the cube display

Figure 1. A sample scene for Test One: Perceived Distance Test

upon the previous experiment, the second test focuses on the benefits of stereoscopy when other depth cues are removed, and the final test is a further expansion of our previous experiment.

The remainder of the paper is structured as follows. Section II presents the methodology of the experiment to evaluate the subject's understanding of the portrayed distance between objects on a cube display with and without stereoscopy. Section III describes the details of the hardware and software used in the experiment. The preliminary experiment is discussed in Section IV, covering both the findings and what improvements were considered for this follow-up experiment. Section V details the main experiment as well as the results and questionnaire. In Section VI the findings and implications are discussed. Section VII presents the conclusion and discusses future work.

II. Methods

The focus of this study was to measure a subject's understanding of 3D distance portrayed on a 2D screen, given different visual cues. The primary objective was to show the benefits of adding stereoscopic depth cues to a cube-type fishbowl VR device. To demonstrate this, three tests were devised. Test One asked the subjects to identify which objects were closest and farthest from a specified object. Test Two was similar to the first but with many customary depth cues removed. Finally, Test Three was a tree-tracing test where subjects were asked to find a node on a branching tree and asked to trace it back to the base of the tree.

A. Visual Cues

The primary depth cues observed throughout this experiment, to a greater or lesser extent, are motion parallax, occlusion, relative size, height in the visual field, and stereoscopy. The visual cue being studied in the greatest depth in this work is stereoscopy.

In nature, each human eye naturally sees a slightly different angle of the same scene. The brain receives these two images and creates the 3D view that humans see when observing the world around them. How the eyes see different images is called stereoscopy. When humans look at a flat object, stereoscopy is not achieved because each eye is seeing effectively the same image.

While moving or observing movement, humans perceive objects closer to themselves as moving faster than objects farther away. This is more prevalent in a vehicle moving at speed and is known as motion parallax. Occlusion occurs when an object is placed in front of another object. When this happens, one object will block vision to some of or all of the other object. This blocking tells our brain which object is nearer to us. Objects whose size is known can be used to compare the size of similar objects. This is the depth cue known as relative size. Finally, height in the visual field is how when a viewer is looking down on a scene, objects farther away appear taller than those closer to the viewer.

B. Test One: Perceived Distance Test

To assess the subject's understanding of the simulated depth within the cube display, a 3D scene was created with four objects positioned within it. This scene includes a green cylinder, a blue sphere, a pink sphere, and an orange cube. Subjects were asked to locate the green cylinder and to identify which objects they felt were closest to the green cylinder and which object they felt was the farthest from the green cylinder.

The objects were set on a white floor and beams were added to mark the corners of this floor. This was done to give the subjects more visual cues, specifically to enhance motion parallax and occlusion. Figure 1(a) shows an example layout for one scene. Subjects did not see this view. Figure 1(b) shows the same scene as it is displayed on one tablet in the cube display.

C. Test Two: Limited Depth Cue Test

Similar to Test One, a 3D scene was created with four spheres positioned within it. The colored spheres were green, blue, pink, and orange. Subjects were asked to locate the green sphere and identify which object they felt was closest to and farthest from that sphere.

(a) Top-Down view from Unity (b) View from the cube display

Figure 2. A sample scene for Test Two: Limited Depth Cue Test

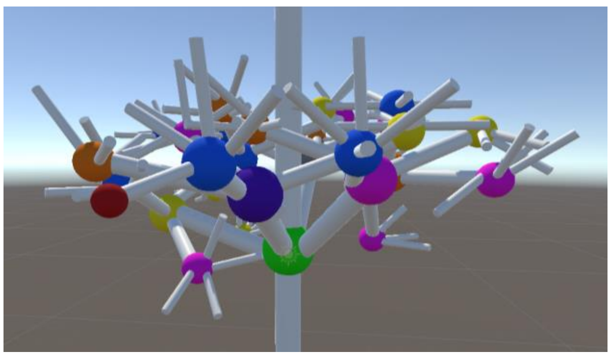


Figure 3. A sample scene for Test Three: Tree Tracing Test

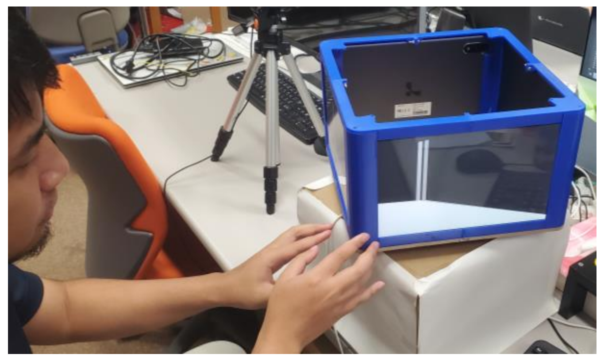


Figure 4. A subject interacting with the cube display

The difference from Test Two is that some depth cues were removed. Specifically, occlusion, height in the visual field, and relative size were either removed or steps were taken to lessen their effectiveness. The objective was to put more emphasis on the remaining depth cues and highlight the benefits of stereoscopy. To achieve this, the floor was removed, and all of the objects were made transparent, removing occlusion. The camera was lowered to no longer look down onto the scene but instead look directly into the scene. Finally, some object's sizes changed between scenes, hindering the effects of relative size. Figure 2(a) shows an example layout for one scene while Figure 2(b) shows the same scene as it is displayed on one tablet in the cube display.

D. Test Three: Tree Tracing Test

A branching tree was placed at the center of the scene, as can be seen in Figure 3. On the trunk of the tree, a green sphere was placed. At the end of one of the outermost branches, a red sphere was placed. These spheres marked the endpoints for the test. Subjects were asked to traverse the tree from one of these points to the other. Colored spheres were placed at each branching point to give the subject a path to follow when traversing the tree.

E. Experimental Procedure

The procedure for the experiment was as follows. Firstly, the subjects were seated at the desk and were told what was expected of them within the experiment. This verbal preparation was followed by a short demonstration of how to interact with the cube display and how to perform the first experiment. Subjects were told to take as much time as they needed and to move as much as they felt was necessary to see the cube from any angle, they felt would help them.

No limit was set for the distance a subject could be from the display. Although the display works best at 45-55 cm in front of the display and within a 40-degree viewing angle in front of the display, the priority was to allow the user to interact with the display in what they felt was a natural way. The optimal viewing distance and viewing area were explained and subjects were told that if they moved beyond these positions, the display may not operate optimally and their immersion might be hindered, but subjects were free to interact with the display as they saw fit. An example of a subject interacting with the cube can be seen in Figure 4.

Each test consists of two parts, with each part comprising half of the scenes designed for the test. The first part of each test was performed with the LFD turned off. The second part was performed with the LFD on. Test One consisted of ten scenes, while Test Two and Test Three consisted of twelve scenes.

When each part of the test was completed, the subject was asked how confident they felt in their choices and why they felt that way. After both parts of the test were finished, the

(a) The cube display was constructed with 3D printed parts

(b) The Encoder and the roller track

Figure 5. The Cube Display setup for the experiment

subject was asked if they felt more confident with the LFD or without the LFD and why they felt that way.

III. HARDWARE AND SOFTWARE USED IN EXPERIMENT

A. Lume Pad

The following research was performed using Leia Inc's Lume Pad, an LFD tablet. As discussed above, the LFD gives stereoscopic depth cues to the user. The tablet possesses a 10.1-inch screen with a resolution of 2560x1600 pixels. To create the light field effect, the tablet displays four images simultaneously and uses lenticular lenses to allow the user to see two of these images at a time. As the user moves horizontally or rotates the cube, each eye will see a new image, thus creating a different view. In this way, three different views are created when the cube is stationary, and stereoscopic depth cues are added to all the other depth cues the subject sees when interacting with the cube.

To generate each of these different views, the Lume Pad uses four images that are divided into a 2x2 grid which is saved as a single image file. This image is then split and placed into the correct locations for the lenticular lenses. Due to the need to put four images into one screen, each image can only make use of one-quarter of the total resolution, so each view has a resolution of 640x400 pixels [5].

A common method of measuring how much detail a screen can show is through pixel density. This is calculated as follows,

$$PPI = \frac{Diagonal\ in\ Pixels}{Diagonal\ in\ Inches} \quad (1)$$

$$Diagonal\ in\ Pixels = \sqrt{Width^2 + Height^2}\ . \quad (2)$$

The width and height pertain to the pixel dimensions of the tablet's screen. In this case, the Lume Pad has a pixel width of 2560 pixels and a pixel height of 1600 pixels. This gives the Lume Pad a natural pixel density of 290 pixels per inch (ppi). When the LFD is used, the width and height are reduced to 640 and 400 pixels respectively. Given these values, the pixel density is about 75 ppi. This comparison appears to be poor because the LFD has 25% of the ppi that the standard tablet, but this is a misnomer due to the tablet being small and having a relatively high resolution. For a more realistic comparison, the LFD can be compared to a standard computer monitor. A popular computer screen size is 24 inches with a resolution of 1920x1080 pixels, giving this screen a pixel density of 92 ppi. This is a much more favorable comparison for the Lume Pad with the LFD turned on, as it has 81.5% of the pixel density of a standard computer screen.

To cope with this reduction in pixel density, the Lume Pad uses some techniques to cause the image to appear clearer than one might expect. The smaller screen size, when compared to a standard PC monitor is one of these techniques as well as the orientation of the lenticular lenses. The lenses in the Lume Pad are not perfectly vertical but instead are slanted slightly. This allows for smoother transitions between views. It has also been shown as an effective method of blending views together to cause the user to believe they are seeing more views than are actually being displayed [6].

B. Cube Display

Using four Lume Pad tablets, a cube display was constructed, as seen in Figure 5(a). It was decided to only utilize the sides of the cube and not the top. The reason for this is that the Lume Pad is designed to be viewed from the front. It is not designed to be placed flat on the table in front of the user and rotated in a circle. If it was used in this manner, the lenses would not work optimally and could display very confusing stereoscopic images. For these reasons, it was decided to limit the displays to the sides of the cube.

Bearings were placed on a track to allow the cube to rotate freely, as can be seen in Figure 5(b). The tablet supports, as well as the track for the roller bearings, were created using a 3D printer. A magnetic encoder was used to track the rotation of the display. The magnet was placed in the bottom of the tray holding the Lume Pads, with the encoder placed on the stationary base and then connected to a PC.

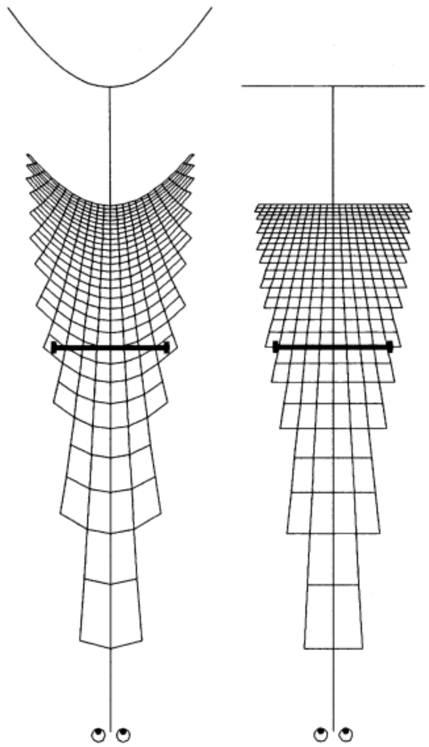


Figure 6. 3D maps of (a) toed-in cameras and (b) parallel cameras versus object distance [8].

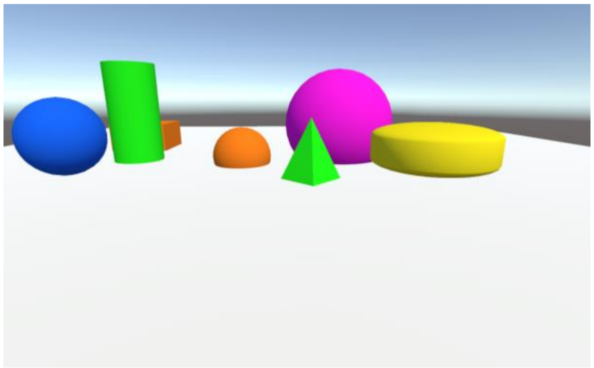


Figure 7. A sample scene from the Preliminary Experiment as seen from one tablet in the cube display

TABLE 1. PRELIMINARY EXPERIMENT ERROR RATE (%)

Subject	Non-LFD	LFD
1	10.0	0.0
2	20.0	10.0
3	20.0	10.0
Mean	16.67	6.67
St. Dev	5.774	5.774
Min	10.0	0.0
Max	20.0	10.0
Median	20.0	10.0
Mode	20.0	10.0

C. *Unity*

The tests performed in this experiment were developed using Unity with the Leia Unity Software Development Kit (SDK) [7]. This SDK is produced by Leia Inc to help developers create applications for their devices. The SDK allows for the utilization of the Lume Pad's features, such as the special Leia camera which creates stereoscopic depth cues, as well as the ability to change the state of the LFD from on to off or vice versa within the test.

The Leia camera consists of four cameras, aligned in parallel with each other. Aligning the cameras in parallel is important to avoid the depth place curvature known as the keystone distortion, which can be seen in Figure 6. This can occur if the cameras are not aligned properly, such as if the cameras are angled inward (toed-in cameras) [8]. This distortion is not as visible when looking at objects close to the viewer, but when looking far away from the user, the image is distorted in a way that does not align with how human eyes naturally see the world and can break the viewer's immersion in the scene.

By using Unity, this allowed a PC to perform most of the necessary computations. This in turn reduced the workload that each tablet needed to perform within the tests, limiting the lag caused by the tablet hardware. Data from the encoder would be sent to the PC, which would do the calculations for camera positions, and then send this information to the tablets via a Wi-Fi connection.

IV. PRELIMINARY EXPERIMENT

In the preliminary experiment, three subjects, all males with an average age of 23 years and normal or corrected-to-normal vision, were asked to perform an experiment similar to the one described above in Test One. Seven objects were placed in each scene and the size difference between each object was much larger, as can be seen in Figure 7. Subjects were first asked to find the green pyramid and choose which object they felt was closest to it. Then they were asked to locate the green cylinder and choose the object they felt was closest to it. Then the scene was changed, the objects were placed in new locations, and this procedure was repeated four more times. After five scenes had been completed, the LFD was turned on and the second five scenes were completed. The data collected was the error rate of each subject in choosing the correct object.

A. *Results*

After the experiment, subjects were asked to fill out a questionnaire to ascertain how well they believed they had understood the test as well as if the test had any adverse effects. The questions were as follows:

TABLE 2. MAIN EXPERIMENT ERROR RATE (%)

Subject	Test One		Test Two		Test Three	
	Non-LFD	LFD	Non-LFD	LFD	Non-LFD	LFD
1	10.0	20.0	41.7	41.7	0	0
2	20.0	20.0	40.0	30.0	0	0
3	10.0	10.0	50.0	20.0	0	0
4	0.0	0.0	16.7	0.0	0	0
5	0.0	40.0	33.3	41.7	0	0
6	10.0	10.0	41.7	8.3	0	0
7	20.0	10.0	33.3	33.3	0	0
8	30.0	20.0	41.7	16.7	0	0
9	20.0	20.0	50.0	30.0	0	0
10	10.0	0.0	50.0	25.0	0	0
11	20.0	10.0	41.7	16.7	0	0
12	10.0	30.0	50.0	16.7	0	0
13	30.0	30.0	50.0	75.0	0	0
14	10.0	30.0	50.0	30.0	0	0
15	20.0	10.0	33.3	25.0	0	0
16	20.0	20.0	50.0	50.0	0	0
Mean	15.00	17.50	42.08	28.75	0	0
St. Dev	8.944	11.255	9.379	17.769	0	0
Min	0.0	0.0	16.7	0.0	0	0
Max	30.0	40.0	50.0	75.0	0	0
Median	15.0	20.0	41.7	27.5	0	0
Mode	10.0	20.0	50.0	30.0	0	0

a. With the LFD turned off, how well do you feel that you understood the scene? Did you know where everything was?
b. With the LFD turned on, how well do you feel that you understood the scene? Did you know where everything was?
c. How confident were you in your understanding?
d. How much discomfort did you feel? Did your eyes hurt? Did you feel sick?

Subjects reported that they felt the scenes were difficult to understand both with and without the LFD. While the LFD helped them to feel more confident in their understanding of the scenes, they were still often uncertain about which of the objects were closest to the green target objects. Most said that they believed that the objects were either too far away or too small to feel confident about their choices. None of the subjects reported any ill effects from the experiment. After the experiment, the subjects were interviewed to try to understand their choices in the tests.

Despite the small sample size, an interesting trend was observed. The number of errors with the LFD cube display was smaller than with the standard cube display, as can be seen in Table 1. A mean error rate of 17% was recorded for the standard cube display while 7% was recorded for the LFD cube display. The standard deviations are the same, and the remaining stats are close to equal as well.

B. Improvements for the Main Experiment

Creating more comprehensible scenes was the most important issue that needed to be addressed in further experiments. More research was done concerning the depth cues that should be the most important for this style experiment. It was decided that occlusion and relative size had not been given enough consideration and had potentially been used incorrectly in the preliminary experiment.

To this end, the size of the objects within the scene was somewhat standardized, making objects roughly three meters tall and three meters wide, using Unity's internal measurements. Previously, the objects had ranged in size from as small as one meter to as large as twelve meters. By standardizing the sizes, subjects could feel more confident in understanding the distance between objects by using the size of objects within the scene as a form of visual measurement.

In the preliminary experiment, it was believed that by placing objects in the scene in such a way as to block some viewpoints, the subjects would need to interact more with the display to understand the distance between the objects. Instead, this caused the subjects to choose answers that they were not confident in. Subjects did this because there were not enough good viewing angles due to occlusion. One method used to address this was to reduce the number of objects in each scene from seven to four. With fewer objects in each scene, more angles were useful to the subject.

Further consideration was also given to how to create a test that would put more emphasis on the stereoscopic depth cues that the LFD can produce. It was believed that by removing other depth cues, more emphasis would be placed on the remaining cues. To this end, Test Two was designed, where occlusion and depth in the visual field were removed as well as relative size being reduced. Given the feedback from the

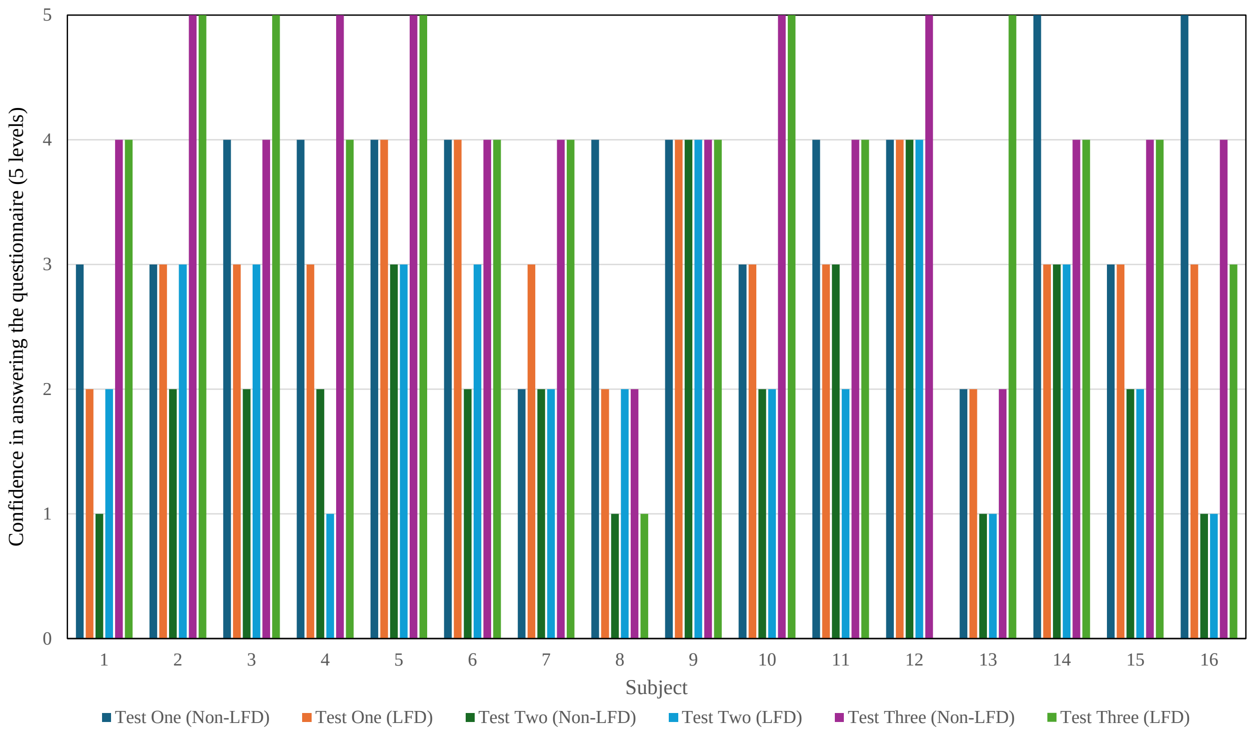


Figure 9. Confidence in answering the questionnaire (5 levels)

preliminary experiment, a lot of care was given to this experiment to make sure it would produce useful data.

V. Main Experiment and Results

Sixteen subjects (six females and ten males) participated in the experiment. They ranged in age from 20 to 31 with an average age of 24 years. All subjects had normal or corrected-to-normal vision. The experiment was carried out over two weeks, and the subjects were asked not to discuss the tests with other subjects.

The subjects performed all of the tests in one session, with the tests performed in the same order. The experiment started with Test One, progressed through Test Two, and concluded with Test Three. In each test, the non-LFD part was performed first and the LFD part was performed second. Every thirty minutes a short break was taken, though most subjects finished before thirty minutes had elapsed. Participants were encouraged to ask questions if they did not fully understand what was expected of them.

A. Scores

The results for Test One can be seen in Table 2. From this table, it can be observed that the non-LFD results were stronger in almost every metric. From this table, it can be seen that the addition of stereoscopic depth cues increased the error rate, standard deviation, maximum, median, and mode. Only the minimum score was unchanged.

A paired samples t-test was performed to compare the error rate between a cube display with stereoscopic depth cues via the LFD and without stereoscopic depth cues. There was not a significant difference in error rate between the cube display without stereoscopic depth cues (M=15, SD=8.944) and the cube display without stereoscopic depth cues (M=17.5, SD=11.255); $t(15) = -0.719$, $p=0.483$.

The results of Test Two were much more encouraging. The results can be seen in Table 2. The error rate decreased when the LFD was active, while the maximum score, median, and mode increased. These results are positive for the LFD, but the standard deviation increased, meaning that the scores have more variance between them, and this is backed up by the minimum score decreasing as well. Neither of these results are positive for the LFD.

A paired samples t-test was performed to compare the error rate between a cube display with stereoscopic depth cues via the LFD and without stereoscopic depth cues when other depth cues are removed. There was a significant difference in error rate between the cube display without stereoscopic depth cues (M=42.1, SD=9.379) and the cube display without stereoscopic depth cues (M=28.8, SD=17.769); $t(15)=3.228$, $p=0.006$.

The results of Test Three were not as promising. Every subject achieved a perfect score on this test which can be seen in Table 2. The reasons for this are addressed in the discussion section of this paper. Since every subject achieved a 0% error rate, no t-test or any other test was performed on these data.

B. Questionnaire

After completing each section of the test, subjects were asked how confident they felt in their answers. These responses were recorded as a score from one to five with five being extremely confident and one being not confident at all. These results can be seen in Figure 9. Subjects were then asked if they felt more confident with or without the LFD, or neither. Finally, once all the tests were completed, subjects were asked if at any point the display cube made them feel sick or uncomfortable and whether or not they felt that the LFD helped their understanding of distance on the cube display. In Test One, ten subjects stated feeling more confident with the LFD off, three stated feeling more confident with the LFD on, and three stated feeling the same level of confidence with and without the LFD. In Test Two, six subjects stated feeling more confident with the LFD off, seven stated feeling more confident with the LFD on, and three stated feeling the same level of confidence with and without the LFD. In Test Three, four subjects stated feeling more confident with the LFD off, eleven stated feeling more confident with the LFD on, and one stated feeling the same level of confidence with and without the LFD.

VI. DISCUSSION

Test One and Test Three did not produce the desired results for reasons particular to each of the tests, while Test Two produced unexpected but useful results. In Test One, many subjects stated that the LFD confused them. Only objects that were at a medium distance were in focus. Objects that were near or far away from the viewer were blurry or sometimes they appeared to be two objects. This caused the subjects to lose confidence in their understanding of the scene. The reason for this became obvious during the interviews and highlights a limitation of LFDs.

A. Test One

The results for Test One were surprising. This test was built upon the preliminary experiment, so it was assumed that the results would follow a similar trend. Instead, the results were the opposite. While these results were not what had been desired, they still were valuable as a learning tool.

When humans look at something, their eyes angle toward that thing, this is called eye convergence. This causes whatever the person is looking at to be in focus while everything else in their field of vision is less in focus. This is essential to how stereoscopy works. LFDs simulate eye convergence with a convergence plane. This sets a focus plane, which can be seen in Figure 10, where objects on or near this plane will be well-defined while objects farther from this plane are in less focus. Objects that are not near the convergence plane will appear to be in a different location for each eye while objects near the convergence plane will appear to be near the same location. Objects that are near the same location appear to be 3D while when each eye sees an object in a different location it causes that object to be blurry or in extreme examples there appear to be two objects.

In tests performed while redesigning the scenes for the main experiment, the convergence plane's position was tested at 5, 10, 20, 25, and 30 meters, but subjects stated that 10 meters felt the most realistic to them. The test area was composed of a square that was 50 meters in length and width, so setting the plane at 25 meters was the original plan, but this caused many subjects to state that they felt dizzy or nauseous. The same feedback was received when the convergence plane was set at both 5 and 30 meters.

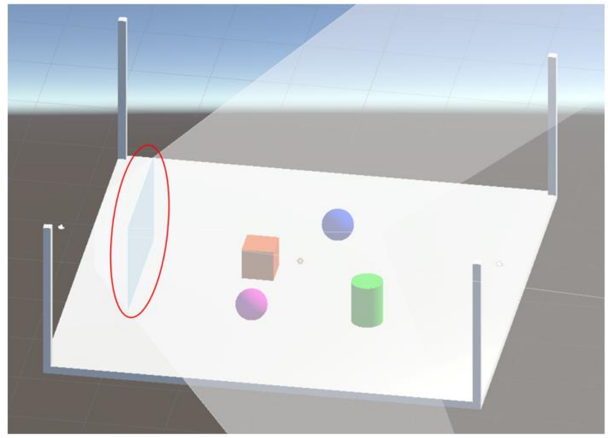


Figure 10. Convergence Plane (red circled area) as shown in Unity

In a 3D scene where objects are placed at any *x* and *z* coordinates, it is not possible to set a convergence plane that covers all objects in the scene. Subjects needed to shift their focus from one object to another to judge the distance between objects, but the LFD could not do that naturally. To combat this, the objects could have been clustered more closely together, which would have helped but not completely alleviated the problem.

Another option would be to allow the subjects to control the position of the convergence plane, but this carries some inherent risk. Based on a small trial, performed after the main experiment's results had been gathered, some individuals feel a sensation of moving when looking at a scene where no objects were in motion but the convergence plane was changing. If the convergence plane changes too quickly it can cause motion sickness, and trying to judge where the plane is located was difficult. Another option would be to allow subjects to choose objects to focus on and allow the software to move the plane accordingly. However, both of these options still cause objects to be out of focus and blurry, so neither is a perfect solution.

B. Test Two

In designing Test Two, a lot of care and consideration was given to the layout of each scene. There was a fear that by removing so many depth cues the scenes would be too confusing for subjects to understand the distance between any of the objects and this would cause the results to be inconclusive.

While the test suffers from the same problems as Test One, subjects stated that with there being fewer other cues to aid them, the stereoscopic depth cues were beneficial to their confidence. At first glance, the results are promising but questionable. When the LFD was on the error rate, median, mode, and maximum scores all increased, the standard deviation went up and the minimum score went down, meaning that the scores were less tightly grouped together but the average score was better. Overall, the results were good.

C. Test Three

The original concept for Test Three was to compare both completion time and error rate. After some preliminary testing, the time comparison was abandoned. This was largely due to three concerns. Firstly, the display is large, heavy, and expensive. Turning the cube quickly risked it falling off the roller track and getting damaged. Another worry is that the encoder might not detect the magnet's rotation and the display would not show the correct images. Also, because of the weight, quick rotations would cause a decent amount of momentum and would be difficult to stop. Again, this increases the risk of damage to the display. Secondly, the Lume Pad's hardware sometimes causes lag or dropped frames. This tablet is designed for portability, not for quickly calculating positions in 3D and rendering images based on those computations. The PC handled most of these calculations, but some work still needed to be done on the tablet. The final constraint was the Wi-Fi connection that was used to transmit the data. While the connection was usually strong, it would occasionally drop a few packets, or in one case, disconnect from the network entirely. These variables can add unintended seconds to each test and would make the results unrepresentative of the actual time taken for each task. For these reasons, the subjects were not timed.

To compensate for the removal of the time comparison from the test, attempts were made to make the test more difficult. The position of the red sphere was often moved to locations that were difficult to see from an accessible angle. It was often placed behind other objects, causing subjects to need to view it from multiple angles to understand where it was, and the path needed to find the base of the tree. However, the test was not difficult enough, as can be seen by the perfect scores achieved by each test subject.

D. Subject feedback

On the questionnaire, four subjects stated that they felt sick or uncomfortable at some point during the test, one subject asked to take a short break during the test before continuing. Many subjects stated that Test Two caused them to feel a little dizzy. Other feedback was very enlightening. One subject stated that the seams of the display, the corners of the cube that hold the tablets in place, were very thick and broke their immersion to some level. Another subject stated that when the LFD was active the edges of the spheres were harder to determine than edges of the cube or pyramid. This suggests that objects with sharp corners make for better objects for stereoscopic depth cues, especially when these objects are not near the convergence plane.

VII. Conclusion and Future Work

In this study, we examined a user's understanding, given some constraints, of a distance displayed on a display cube utilizing LFDs in an attempt to show that the human brain understands distance better with the inclusion of stereoscopic depth cues than without them. It was shown that using an LFD to display stereoscopic depth cues increased subjects' understanding of the simulated distance over when the cube did not display stereoscopic depth cues when other depth cues were removed or suppressed. The t-test results from our second test allow us to state this with confidence.

A comparison of our results can be made to the findings of Reising and Mazur [9]. In their research, pilots performed an airspace disambiguation task, in which the subjects were shown a battle situation display with and without stereoscopic depth cues. Subjects were asked to identify the number of aircraft in a given area in a target group. For example, a pilot might be asked to tell the number of friendly aircraft in the quadrant that is in front of and above the pilot's aircraft. In their study, it was shown that the addition of stereoscopic depth cues did not provide a benefit, except for when other depth cues were limited. These results align with the results from our study.

Another study that has comparable results to ours is that of Ntuen et al. [10] as it resembles Test One. In their study, a cone and three colored spheres were added to a scene from Google Maps and users were asked to identify which sphere was closest to the cone. This test was performed with and without stereoscopic depth cues and then the results were compared. The results showed that adding stereoscopic depth cues did not produce a significant improvement, which is what our results in Test One showed as well.

An improvement that can be applied to the entire experiment is to improve the refresh rate of the tablet screens used in the display. The displays generally would operate at thirty frames per second but, as discussed in the previous section, sometimes the screens would lag. Further optimizations can be made to the tablets when rendering the scenes. If this lag can be brought low enough, recording the time it takes for each subject to complete each task would be very beneficial. Response time comparisons could be made not just between with and without the LFD, but between Test One and Test Two as well. These results could show us which depth cues are the most beneficial in a subject's understanding of the 3D scene.

To further this experiment, firstly modifying Test One is a high priority. Enlarging the objects and bringing them closer together would fix some of the problems that the test suffered from. It will not fix all of the problems but based on the results and feedback from Test Two, it should fix enough of the problems that we will obtain better results.

An idea for enhancing Test Two is to create tests where only one of the depth cues is removed, such as only removing occlusion or height in the visual field. This would help to isolate the benefits of the LFD and maybe can highlight if other depth cues are more important.

Finding a method to alter Test Three is more difficult. Seeing as many of the problems encountered are related to the hardware, creating a dedicated device would be the obvious response. An LFD display cube designed from scratch could be made lighter and with better hardware. Hopefully, the lag will be overcome. The device could also be made to be lighter, allowing for a user to carefully pick it up and interact with it instead of it being attached to a track and only rotating on one axis. The drawbacks of this idea come down to the cost and complexity of LFDs. Even if the cube is easier to interact with, a great amount of care would need to be taken when handling the cube.

Comparisons can be made between our work and that of Stavness et al. [11] with their pCubee device. This is a cube display from which we drew a great deal of inspiration. One of the key differences is that pCubee uses a head tracker to create a realistic 3D experience by tracking where the user's head is and adjusting the screens accordingly. Without any form of head tracking our display works similarly, but only to a point. The current LFD works with horizontal movements but does not work with vertical movements. Without adding a form of user or more advanced device tracking this cannot be added. This is something that should be strongly considered going forward. With a redesigned device more complex device tracking can be achieved. If the device can track how high it is lifted or tilted, then the displays can compensate for this and reproduce these changes within the display. This would allow our cube to deliver a stereoscopic experience without the need for any form of user tracking.

If a form of user tracing was to be added, eye tracking would be the most beneficial, though the implementation would be very complicated. More advanced LFDs use eye tracking to adjust the images used in the LFD to create a smoother 3D experience for a single user [12]. Based on feedback, one problem with the cube display was that if the subject moved while the display was stationary, the 3D image would not shift seamlessly. While moving from the area where one image is displayed and into where another is displayed, the view would occasionally become confusing. Moving a short distance to either side solved this issue, but creating a smoother experience would still be beneficial.

Another area that has not been explored is the potential for multiple users to interact with the LFD cube display. Since an LFD has an optimal viewing area and is not tethered to a single individual, multiple users can experience the stereoscopic depth cues that the LFD produces. A test that can ascertain two or more users' understanding of the depth cues visible on the display cube would be compelling. Either a test that requires multiple users to interact with the cube, or a test that requires users to cooperate to succeed would be an idea for these tests. More research needs to be done to determine the best type of test to achieve satisfactory results. Also, this cannot be used natively along with eye tracking. If the images on the display are changing for one individual, any other individuals will see a moving scene that they are not interacting with. An option to address this would be the addition of a way to isolate the view that each subject can see such as shutter glasses.

A final area that should be explored is to look at other methods of interacting with the display cube. pCubee could be interacted with such as a stylus and a PC mouse. In a 3D tree-tracing task, the researchers found that the fastest mean user response times were achieved with a combination of pCubee and a PC mouse while using only pCubee resulted in the slowest mean response times. A comparison between the findings of pCubee and this cube display would be enlightening.

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The Apprentice Copilot

The Untapped Potential of Using Generative Artificial Intelligence by Design Students

Short Paper

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***Abstract*—This research is part of an investigation into the use of Generative Artificial Intelligences (GenAI). Through a case study, we analyze both the use and abstention of these tools by students in the creative area during the resolution of a graphic challenge. The study underscores the importance of developing skills in emerging technologies to foster innovation. The central question explored is how GenAI tools are employed in the co-creation process and the development of design solutions. The main findings indicate that, despite their potential to act as copilots in the conception and creation process, these tools are still underutilized by students in this specific case study.**

Keywords-Generative AI; Artificial Intelligence; Hackathon; Creative Industry; AI Copilot.

I. Introduction

In recent years, Generative Artificial Intelligence (GenAI) has been significantly reshaping workflows across a wide range of economic sectors. Its ability to assist in creative processes and problem-solving has provided new opportunities for exploration, particularly in education and design. Therefore, this research aims to investigate how students utilize GenAI as an innovative tool to address and solve creative design challenges. This article presents a detailed case study [1] of a hackathon-style event conducted as part of a digital innovation project course within the Bachelor's Degree in Design at the Federal University of Santa Catarina (UFSC). The participants, fifth-semester Design students, were divided into five groups of two. Each group faced the challenge of delivering two graphic solutions: one created using traditional methods and another incorporating Generative AI tools.

The event was designed to examine how students incorporated generative AI tools into their creative processes, evaluated whether these tools supported or hindered their workflows, and understood their perceptions regarding this integration. To facilitate a consistent analysis, both stages of the challenge were based on the same theme. The central focus aligned with the United Nations' 13th Sustainable Development Goal: Climate Action. Students were tasked with addressing the question, "How can we promote awareness about the preservation of the Amazon Rainforest?".

As part of the event, students created an image to represent a solution to the proposed challenge. A jury evaluated the submissions using predefined criteria (outlined in the Methods Section) to select and award the work that best addressed the challenge. The first 50 minutes of the activity were dedicated to solving the challenge exclusively using traditional methods, which the students were already familiar with, without the assistance of GenAI tools. After a 10-minute break, the participants resumed the same challenge for an additional 50 minutes, where they were allowed to incorporate GenAI tools at any stage of the process, from ideation to final design.

This research explored how GenAI tools were integrated into students' creative processes and their impact on design outcomes. To address this matter, a Case Study methodology was employed (as detailed in the methodology section) to examine qualitative data gathered through a structured form completed by the participants. The goal is to analyze the experiences, perceptions, and outcomes reported by the students, providing an understanding of the factors that contributed to the success or failure of the event's challenges. The paper is structured as follows: In Section II, we present the theoretical framework underpinning our study, exploring prior research related to AI in the creative process. Section III details the methodology employed, including the research design, data collection, and analysis techniques used to gather and interpret the data. In Section IV, we provide a comprehensive analysis of the results, discussing the implications and significance of the findings. Section V addresses the limitations of our work. Finally, Section VI presents our conclusions.

It is important to emphasize that this study is inherently qualitative, and its findings cannot be generalized or used to establish a definitive consensus on the use of AI-generated tools by students. Rather, they represent the initial phase of an effort to investigate these applications. In this sense, the sample of 10 students serves as a pilot experiment, enabling future studies to be replicated or refined based on the format adopted in this initial approach. Thus, we advance the discussion on the uses and non-uses of these tools, expanding our understanding of their implications and possibilities.

II. Theory

AI tools have increasingly been used in the design and creative industry, focusing on content creation, information analysis, content enhancement, information extraction, and data compression [2]. It has also been transforming visual processes through creating concepts, styles, and aesthetics [2].

AI tools that generate images, also titled "text-to-image", such as Midjourney, Adobe Firefly, and DALL-E have been investigated in the field of design for their specific applications in image creation. Recent literature shows that these models are capable of producing highly realistic and aesthetically pleasing images demonstrating significant potential for aiding in artistic creation and productivity, making content creation more accessible to non-specialized users [3]. Certain text-to-image GenAIs are positively rated on user experience (UX) metrics, such as ease of use and intuitive design [4]. As Artificial Intelligence plays a significant role in culture in general by assisting in aesthetic decision-making related to media creation [5], these AI tools are particularly relevant for content creators and creative fields.

The literature also presents different cases within creative domains especially in design [6][7], art [6][8] and architecture fields [9]. However, while investigations within creative industries and professional contexts presents insights over increased productivity and enhanced creativity [10], studies on the impact of AI focusing on students in creative areas seem comparatively less researched. Moreover, considering the recency of Generative AI, there is still considerable scope for further investigation. Among recent studies focusing on students, investigations about the satisfaction with the results generated by GenAI tools suggests that they need significant improvements in usability and positive emotional resonance to meet the expectations of future designers [4]. Other studies assert that Generative AI tools can enhance the creativity and aesthetic capabilities [11] and reduce the cognitive load of design students [12].

III. Methods

This research constitutes a case study [13] and adopts a fundamentally qualitative approach to understand the subject matter. The primary instrument for data collection involved the use of structured questionnaires, designed to capture comprehensive feedback about the event. The questionnaires were administered to participants following the event. To enrich the depth of the discussion, the data collected through these questionnaires were further supplemented by the researchers' participant observation to provide contextual insights that were not captured through the questionnaires alone. Additionally, document analysis of the jury's evaluations was conducted, to enhance the robustness of the findings. The event thus included the participation of students, mentors, and the jury.

At the beginning of the Hackathon challenge, participants were provided with basic instructions regarding the deliverable. The deliverable format consists of two submissions per group: one developed using GenAI and the other developed solely with traditional design methods and tools, at the participants' discretion. Therefore, students were allowed to use any software tool to create, as long as it did not incorporate any AI functionalities for the first challenge. For the second challenge, various AI tools were suggested to assist the students, including Adobe Firefly, Copilot, Gemini, Midjourney, Photoshop, Illustrator, and ChatGPT. This way, students could choose at which stages of the design process to use these tools, whether for generating ideas through text or for creating or editing images.

The file format was restricted to JPEG or GIF and only free images repositories or images created by themselves were allowed. The students were organized into five groups, and each group had access to one computer to perform the tasks, with a time limit of one hour for each proposed challenge.

The theme of the challenge was "How to promote awareness about the preservation of the Amazon Rainforest?" for both deliverables. This format enabled direct comparison of deliverables created with and without GenAI, aligning with the United Nations Sustainable Development Goal 13: Climate Action. Fig. 1 represents the challenge that the students were required to use as the main theme for their creation.:

Figure 1. Challenge proposed to Design students.

The jury, composed of three individuals, including two designers and one advertising professional, consisted of two doctoral students and one master's student. They assessed the materials in a separate room using a Google Forms questionnaire. The evaluation interface categorizes the projects according to three criteria, with scores ranging from 1 to 5, where 1 is the lowest and 5 is the highest, as follows:

- Originality and innovation: Evaluation of the uniqueness and creativity of the approach to the theme, whether the proposal offers new perspectives or unconventional solutions to the challenges faced by the region, using novel or underexplored technologies or concepts.
- Visual communication: The visual composition of the solution, if it tells an engaging and informative story about the theme. Observation of the ability to convey a clear and persuasive message through visual elements, layout organization, and use of colors.
- Clarity of the message: Evaluation of the clarity with which the solution communicates its main message or call to action regarding the theme, whether the message is easily understandable, direct, and capable of mobilizing the audience for the cause, avoiding ambiguities and ensuring that viewers comprehend the objectives and importance of the challenge.

Additionally, to ensure an impartial evaluation of the relationship between participants and jury, the teams and the deliverables were anonymized. Works were submitted to the judging panel under randomly assigned letters from A to J. The jury was not informed about which deliverables were created with the use of AI. This decision was made to ensure impartiality in the evaluation process, allowing the jury members to assess each submission based on the pre-defined criteria.

Participant observation, conducted by the researchers, also formed part of the conclusions in the study. This approach offers the observer the opportunity to avoid solely perceiving elements that conform to their implicit or explicit hypotheses, thus leading to a genuine questioning [13]. Therefore, by exploring the significance and utilization of the elements and distinguishing its applicability, the observers improve their analytical framework [13]. In this context, the researchers were able to identify how the AI tools were used and not used by the students, which significantly influenced the final product outcome.

After the event, the instrument for collecting qualitative data from the students was distributed. This collection tool consisted of seven questions, the answers to which will later be discussed in relation to the experience of the event. In conclusion, the participant observation experience complemented the qualitative analysis of the data collected through the forms. Specific aspects observed, such as the decision to not use AI tools to generate content at certain stages of the process, were highlighted and later clarified by the students in the forms.

To evaluate the students' previous understanding and use of Artificial Intelligence, we administered a pre-hack questionnaire at the start of the course, which included two targeted questions related to the upcoming activities. Students were asked whether they had any experience with Generative Artificial Intelligence for creating and editing images and, if so, to specify which AI tools they had used. The AI tools mentioned included Midjourney, Canva text-to-image, Firefly, Copilot, and DALL-E

IV. Analysis

Based on the responses provided by the students, it was possible to assess their level of familiarity with Generative Artificial Intelligence tools. This analysis revealed initial indications that these tools were still being underutilized. The analyzed data suggests that students may have limited experience about the available tools. Fig. 2 presents a summary of the students' prior experience.

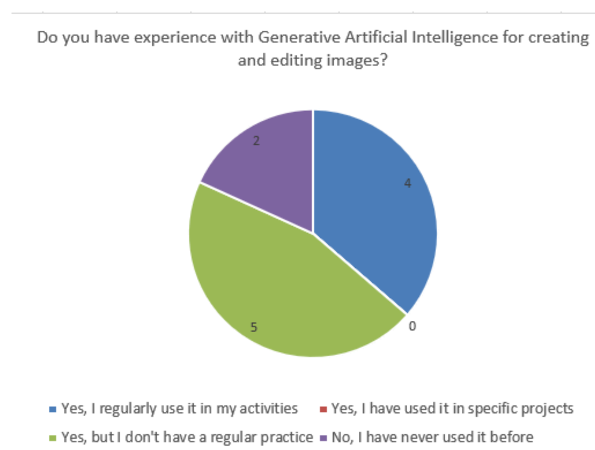

Figure 2. Students' prior experience with GenAI for creating and editing images.

Fig. 3 and Fig. 4 compiled the students' works with and without AI usage, showcasing the diverse creative efforts and perspectives of each group. In Fig. 3, it is possible to observe the images created using traditional methods and tools.

Figure 3. deliverables created by design students, without AI.

Each group focused on different aspects of the challenge. While one group advocates for reducing meat consumption with the slogan “One day without meat, one step for the Amazon" (top left corner), another highlights critical reasons to fight for the forest with “Why fight for the preservation of the Amazon?” (top center). Other groups underscore the destructive consequences of deforestation with slogans like “Keeping what remains standing is not enough” (bottom left corner) and “Destroying the Amazon is destroying our roots” (bottom center). Some of the students submitted static images while one group chose to create a video in GIF format. Comparatively, Fig. 4 contains the five distinct images created with the assistance of AI tools.

Figure 4. deliverables created by design students, with AI tools.

The first image (top left corner) has the text “without preservation, the Amazon will be just a story told in theaters”, created by the same group that had previously made a deliverable in GIF format. For the second challenge, this group decided to create a completely new image with a different approach.

Some groups maintained the same challenge idea for the AI-assisted part, keeping the same slogan, for example the second image (top center), that includes the text “keeping what remains standing is not enough”, the third image (top right corner), with the text "why fight? for the preservation of the Amazon” and the image in the bottom center, “one day without meat, one step for the Amazon”. All of those images were created using Midjourney and Firefly, also edited with “traditional” tools such as Canva and Photoshop.

The fourth image (bottom left corner) has the text “don't let greed destroy the Amazon”, showing hands breaking a tree branch. This image represents a hand-drawn illustration and is particularly noteworthy because the group chose not to use AI text-to-image tools to create it, opting for traditional methods like hand drawing instead. In this case, AI was only used for ideation and brainstorming with ChatGPT.

Each project was scored using the three predefined criteria: Visual Communication, Clarity of Message, and Originality and Innovation. Both the highest-rated project and the one with the lowest score were completed without the use of AI generation, while the projects with scores closest to the sample average were those created using AI tools. Notably, the project with the highest overall score was the only deliverable submitted in GIF format, whereas all others were in JPEG format. This observation suggests an improvement for future research: the need to establish a standardized deliverable format to minimize potential biases in the evaluation process. Table I represents the average score and the category of each of the project, analyzed by the jury.

TABLE I. TABLE TYPE STYLES

Jury Evaluation					
Code	***Visual Com.***	***Clarity***	***Orig. / Innov.***	***Total***	***Category***
C	4.0	3.7	5.0	12.7	Without GenAI
B	3.7	2.7	4.0	10.3	Without GenAI
E	3.7	2.7	4.0	10.3	Without GenAI
D	3.3	3.3	2.7	9.3	With GenAI
H	3.3	3.3	2.3	9.0	With GenAI
G	3.3	2.7	3.0	9.0	With GenAI
J	2.7	3.3	2.7	8.7	With GenAI
A	2.7	3.0	3.0	8.7	With GenAI
I	3.0	2.7	2.7	8.3	Without GenAI
F	2.7	2.7	2.7	8.0	Without GenAI

The work with the highest score, achieving 12.7 total points among the jury members, was done without the use of GenAI. Conversely, the work with the lowest score, also without the aid of GenAI, reached a total of 7.0 points. These results constitute a standard deviation of 0.97, which suggests that the evaluations were relatively consistent.

As mentioned, after the event, a structured questionnaire was submitted to the participants, containing the following questions:

a) Were you already familiar with generative AI tools for use in design processes? If so, which ones?

b) At what stages of the process/challenge did you use AI? Please describe which tools you used and how you utilized them.

c) What are the main tools you typically use in your traditional creation processes?

d) What were the main challenges you encountered in the task without the use of AI?

e) What were the main challenges you faced in the task with the use of AI?

f) After completing the challenge, did any new questions arise about the use of generative AI in the design process?

g) What did you think of the activity? Please leave your overall feedback.

The qualitative analysis of the data from this questionnaire, along with the participant observation, provided insights for several key inferences. Firstly, regarding the students' complaints about insufficient time to complete the challenges, participatory observation revealed an acceleration of the process in the initial stages of ideation and drafting. In the final phases, the students showed little interest in exploring new images with the remaining time. Indeed, three of the five groups completed the activity before the initially scheduled deadline. It was also observed that participants had limited knowledge about GenAI tools, with only two of them stating they had prior experience with these types of technologies. The others reported a basic familiarity with some tools, such as Adobe Firefly and Photoshop Beta, but had not effectively used them previously.

One of the main challenges identified both in the questionnaire and in the participant observation was the students' lack of prior knowledge in formulating appropriate prompts for image creation. This specific challenge was also identified in previous literature about GenAI content creation with students, where the need for further research in developing effective prompt strategies is highlighted [14]. For instance, one participant entered the input expecting the GenAI to produce a literal representation of the final challenge result. This approach was also observed in other groups. Three respondents mentioned using ChatGPT to refine the prompts before inserting them into the GenAI. From this perspective, we observed students cannot expect AI tools to produce fully polished results; rather, these creative process outcomes must be refined by human intervention. This also aligns with existing literature that emphasizes the role of AI as a tool or collaborative assistant for creativity, rather than a sole creator of original work [14][15].

Secondly, comments from students, such as "I did not get exactly what I was imagining" and "the images did not turn out as we wanted", expressed in the answers of question 05, illustrate the difficulties encountered in constructing and refining prompts. Similarly, question 06 highlighted their low familiarity with the interfaces of the tools, as expressed in comments, such as "How to use the tool correctly so that it produces art more faithful to the ideas we have" and "I feel I need to practice more with the tools to learn to think about prompts more effectively".

For example, one group stated that Adobe Firefly was used for creating campaign images, while attempts to utilize generative AI within Illustrator for refinement were ultimately unsuccessful, leading to the creation of a new artwork from scratch, supplemented by text from Canva. Another group decided not to use GenAI for the graphic stage of the second deliverable, preferring more traditional tools because they felt more confident in their use. Therefore, this group used ChatGPT exclusively for immersion and idea generation, abstaining from using AI in the creation of the final deliverable.

Overall, participants found generative AI useful for idea generation and structuring, but encountered challenges when using it for final image creation, preferring traditional design methods or tools for achieving desired outcomes. In summary, despite the initial assumption that GenAI is already being used as supportive tools in the conception and creation of graphic projects by students, the results of the experiment indicate that these tools are still underutilized in the creative process. However, the participants showed interest in deepening their knowledge of the tools and developing their skills to enhance their performance.

From the responses to the questions mentioned above, the students highlighted some difficulties within the event, among which are notable:

- The limited time available for completing the challenges;
- The students' low level of prior knowledge regarding the use of GenAI in design processes;
- A lack of experience in constructing prompts;
- Limited familiarity with generative AI interfaces.

These challenges primarily occur, according to the students, due to a lack of digital literacy for the use of generative tools and a lack of experience in formulating effective prompts, resulting in low-performance use of the available technologies. The students also showed a clear preference for traditional design methods to achieve the desired results possibly because they are familiar with these tools in their ideation and creation processes. As observed in similar studies, the tools can provide AI-supported co-design, but designers need to enrich their skills to effectively "collaborate with the AI partner" [16].

Meanwhile, when performing activities using GenAI tools, students showed less concern about time, as artificial intelligence guided them more swiftly to final solutions. The stages of the design process (immersion, ideation, prototyping, and development) were perceived by students as being set aside or 'swallowed' by GenAI. Despite the difficulties identified through participant observation, we noticed the students' interest in enhancing their GenAI skills to apply them in their creative processes. Investing in the training of students, both in terms of technical knowledge and in the crafting of good inputs through prompting, can promote a broader and more sophisticated use of these tools, aligning with contemporary trends that see AI as a copilot in the design process.

V. LIMITATIONS

It is important to emphasize that this study represents the beginning of an investigation with hackathons and students from creative fields, and has some limitations. First, its results are based on a small quantity of data and cannot be generalized. Additionally, the study was conducted within a single educational institution, which may not fully capture the diverse ways students from different backgrounds and contexts engage with

Generative AI tools. Finally, as this is a qualitative study, the insights provided are interpretative and may not comprehensively reflect all the nuances of the participants' experiences. It is also worth noting that the students involved in the activity are from the fifth semester of the Design program. However, it provides insights for advancing the discussion through a scientific and experimental approach. The data analysis was conducted by three researchers who monitored all stages of the study, from its conception to execution, and also gathered valuable information through participant observation during the experiment. Future research could address these limitations by expanding the sample size, incorporating other methods, and exploring diverse educational settings to enrich the understanding of GenAI's role in creative education.

VI. Conclusion and Future Work

GenAI have made significant advancements recently and have captured the interest of the academic and scientific community due to their disruptive potential, which reinforces the relevance of research on the subject. In this study, we investigated how students in the creative field use AI tools in graphic challenges. Based on our sample, the students are still not familiar with the techniques and GenAI tools in their daily workflows. This provides an opportunity to the development of training programs that enable them to effectively appropriate these technologies to optimize their creative processes.

It was observed that, although there was an initial advance in the ideation and drafting phases, the students faced considerable challenges due to a lack of prior knowledge and experience both with the technology itself and with formulating effective prompts for image generation. This often resulted in unsatisfactory outcomes, as highlighted by the students' comments about the discrepancy between their expectations and the images produced. Therefore, the implementation of GenAI tools in educational contexts requires a well-structured strategy that includes both technical and creative preparation, ensuring that participants can effectively use these tools.

This first stage of our investigation into creative challenges points to future theoretical-methodological advancements, suggesting an expansion of the sample size to increase the robustness of the findings and enabling the replication of the study across different creative domains for comparative purposes. Additionally, it is recommended that future educational initiatives include training programs focused on prompt strategies as well as on the creative and strategic use of these tools, aiming to reduce the gap between expectation and outcome and to explore more comprehensively the conditions under which Gen AI can be better utilized in creative educational environments, considering different contexts and skill levels.

We conclude that, despite the great potential of Gen AI as an auxiliary tool in the creative process, its effective implementation in educational contexts requires a systematic and integrated approach that addresses both the technical and pedagogical development of students. In this way, it will be possible to promote a more robust and innovative use of these technologies, aligned with the needs and expectations of future professionals in the creative field.

Acknowledgment

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

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