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About Mada

Mada – Assistive Technology Center Qatar, is a private institution for public benefit, which was founded in 2010 as an initiative that aims at promoting digital inclusion and building a technology-based community that meets the needs of persons with disabilities (PWDs). Mada today is the world's Center of Excellence in digital accessibility in Arabic.

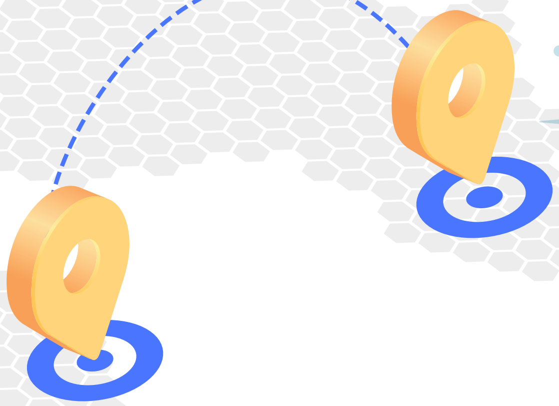
The Center works through smart strategic partnerships to enable the education sector to ensure inclusive education, the community sector through ICTs to become more inclusive, and the employment sector to enhance employment opportunities, professional development and entrepreneurship for persons with disabilities.

The Center achieves its goals by building partners' capabilities and supporting the development and accreditation of digital platforms in accordance with international standards of digital accessibility. Mada also raises awareness, provides consulting services, and increases the number of assistive technology solutions in Arabic through the Mada Innovation Program to ensure equal opportunities for the participation of persons with disabilities in the digital society.

About Nafath

Nafath aims to be a key information resource for disseminating the facts about latest trends and innovation in the field of ICT Accessibility. It is published in English and Arabic languages on a quarterly basis and intends to be a window of information to the world, highlighting the pioneering work done in our field to meet the growing demands of ICT Accessibility and Assistive Technology products and services in Qatar and the Arab region.

Content Page



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Open call for papers

"Nafath" an open access journal, solicits original research contributions addressing the accessibility, usability, and key information resource for disseminating the facts about latest trends and innovation in the field of ICT Accessibility to enable persons with disability and the elderly. Nafath is focusing on the theoretical, methodological, and empirical research, of both technological nature, that addresses equitable access and activate participation of potentially all citizens in Information Society.

Topics of specific interest

Important aspects and topics to be discussed evolve around (but are not limited to):

- Accessibility guidelines
- Accessible games
- Adaptable and adaptive interfaces
- Alternative and augmented Input /Output techniques
- Applications of assistive technologies in the mainstream
- Architectures, development methods and tools for ICT Accessibility
- Design for All and accessibility education and training
- Evaluation of Accessibility, Usability, and User Experience
- Innovative Assistive applications and environments and ICT Accessibility solutions
- Localization
- Novel designs for the very young, the elderly, and people with different types of disabilities
- Novel interaction techniques, platforms, metaphors, and devices
- Personalization techniques and personalized products and services
- Smart artifacts, smart cities and smart environments
- Web accessibility

In addition to the above, Nafath can host special issues, book reviews and letters to the editor, announcements (e.g. conferences, seminars, presentations, exhibitions, education and curricula, awards, new research programs), and commentaries (e.g. about new policies or legislation).

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Fostering Tech Acceptance:
User Experience in E-Gov Services as Path to Digital Transformation
A comparative analysis: Qatar and Singapore

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Keywords
Digital Transformation (DT); Information and Communication Technology (ICT), User Experience (UX); Citizen Experience (CX); Customer Experience (CX); E-Government Services; Technology Acceptance; Qatar; Singapore.

Abstract - Qatar and Singapore are small nations, collaborate in Digital Transformation (DT), innovation, public administration initiatives. Despite both countries advancing in ICT infrastructure, challenges in technology adoption differ. This study investigates UX impact in the main e-government websites on technology acceptance and DT maturity in both countries. By clarifying UX main enablers make Singapore more advanced in technology acceptance, that leads to higher DT maturity than Qatar continues to face challenges even with the ongoing efforts. The study focuses on understanding user behavior toward technology by using UTAUT model. The comparative analysis of Qatar's "Hookumi" and Singapore's "Developer, using automated tools and manual reports from United Nations and World Bank datasets. The findings show both platforms highlight similarly the role of performance, effort expectancy and facilitating conditions as Internet broadband to behave users toward technology this impacts DT, but social influence was not clear despite both prioritize citizen satisfaction. Qatar advances in accessibility, investing in e-health and e-education services but faces with obstacles in unified e-services platform, technology adoption, and data

fragmentation. Singapore demonstrates best practices has effective “one-stop” platform, user-centricity research center, data integration and e-financial services with high CX. The research contributes UTAUT factors influences the value of UX in e-gov services driving technology adoption. The study recommends Qatar’s policy and decision makers should make integrated e-services with accurate data, establish a research center to address users’ challenges through e-participation and focus on digital literacy to foster DT. While Singapore should enhance accessibility standards as compliance. Both countries should enhance UX testing by involving diverse users including disabilities and AI tools partially. The study guides practitioners, researchers, and institutions to benefit from UX insights to collaborate and make practical partnerships and future research to resolve the limitations, as result the importance of UX in DT journey success.

Fostering Tech Acceptance: User Experience in E-Gov Services as Path to Digital Transformation.
A comparative analysis: Qatar and Singapore

1. Introduction

Few countries prioritize citizen-centric and universally accessible services, with limited citizen involvement in portal design. Only around 40% provides accessibility features for disabilities users, a gap evident even in high-income economies (GovTech Maturity Index, 2022). In 2019, World Bank established GovTech Global Partnership (GTGP) to promote digitalization, citizen-centric solutions, engaging governments, private sectors, academia, and development actors (Govtech Global Partnership, 2022). However, the digital gap widens as the Global Technology Maturity Index (GTMI) increased from 0.519 to 0.552 in 2022, reflecting advancements in online service delivery via shared platforms (GovTech Maturity Index, 2022). Administrative efforts to enhance e-service quality, particularly for Gen Z are imperative (Agritika et al., 2024).

Despite available Information Communication Technology (ICT) infrastructure, technology projects failures necessitate examining user pain points during e-service utilization and adopting a user-centric perspective by engaging users for iterative enhancements when initiating or renewing services to achieve better UX and meet stakeholder needs (Chatzidakis, 2022; Usability Evaluation, 2023). As Steve Jobs properly stated, "you've got to start with the customer experience and work back toward the technology, not the other way around," underscoring the significance of UX (Guide User Experience, 2023). Central Asia and Europe have advanced GovTech maturity, but Middle Eastern service delivery and citizen engagement face challenges despite progress (GovTech Maturity Index, 2022).

Regardless of the country, citizens often avoid visiting government websites due to outdated interfaces (Researchers, 2022). However, during COVID-19 pandemic increased pressure on governments. This situation arises because some government agencies lack competition, DT investigation, and maintenance teams. Consequently, people visit these sites only for tasks or information. National Digital Transformation Committee (2022) noted low user profile creation on national E-Services Portals (ESP) concerning the Provincial Governance and Public Administration Performance Index (PAPI), indicating user-unfriendly e-government service interfaces' challenges (Enhancing User-Friendliness, 2023). Addressing digital divide and e-service limitations is crucial, along with monitoring usage not just assessing to enhance transparency, citizen engagement, and resilience through DT by public agencies (GovTech Maturity Index, 2022). As a result of the COVID-19 outbreak, societies were compelled to adapt to the digital era through policies that supported this trend (Park et al., 2022).

In our research, we hypothesize that user-friendly and easy-to-use of e-government services positively impact people's attitudes and usage behaviors toward accepting technology, further promoting DT. Studies on e-government service acceptance overlook government efforts to enhance UX with digital services (Kumar et al., 2017). Employing UTUAT framework to test hypothesis and explore how e-service simplicity impacts citizen acceptance of technology and contributing to DT maturity by assuming Singapore advances on Qatar. Analyzing published platforms by automated tools and secondary data from UN and World Bank reports, we assess complex user interfaces' impact on UX and technology acceptance in Qatar and Singapore's e-platforms. The importance of web analytics metrics is utilized to understand current content and user motivations and needs, although we cannot comprehend the reasons behind those actions (Dumas & Loring, 2008). Analyzing government websites from a user perspective bridges theory-practice gaps, identifying digital service maturity, citizen participation, lessons and challenges, and creating public administration value through UX analysis across contexts.

First, the paper will review literature, exploring conceptual and theoretical framework; Digital Transformation, e-government, and UX in e-services. Using the UTAUT framework will examine the relationship between user acceptance behaviors and technology utilization. Second, it will examine the current status of GovTech initiatives and relative global indices in Qatar and Singapore through a comparative analysis. Third, the methodology section will detail data collection and sources used for analysis and result generation. Fourth, we will highlight the limitations and contributions of our study. Fifth, we'll analyze e-government platforms in Qatar "Hukoomi" and Singapore "developer". Singapore demonstrates superior performance, best practices, compliance, and data integration, while Qatar excels in accessibility despite fragmented data. Differences in citizen participation, perception of simplicity, and demographic moderators influence technology acceptance and e-service maturity. Understanding the advancements and obstacles in both countries and their impact on DT is crucial. Sixth, we'll discuss theoretical and practical contributions and limitations. Lastly, offers recommendations and insights to help ensure the DT journey is a success for users, which is a top priority for government organizations, policymakers, developers, and future researchers.

2. Background

2.1. Conceptual and Theoretical Framework

2.1.1. Digital Transformation and E-government and User Experience

Digital transformation (DT) is not just implementing technology projects; it involves integrating technology across organizational and institutional changes, driven by business goals and customer needs strategically (Bloomberg, 2018). Participants prioritized data-driven and customer-centric outcomes for meaningful business results (Cohen & Neubert, 2019). DT emphasizes the user, while technology is the focus of digitalization and digitization. Information is handled by digitization, operations are managed by digitalization, and an organization's entire strategy is driven by DT (Bloomberg; 2018). So, governments derive advantages from ICT to improve and expand services across various sectors, including healthcare, education, and the economy by emerging new concept "e-Government" (Kartik et al., 2016).

E-Government (e-gov) refers to the use of technology and Internet applications to offer services to society (citizens, employees, governmental entities, private sector, and related organizations) (Layne & Lee, 2001, p. 123, Svärd, 2017). United Nations (UN) initially defined e-Government as using ICT for online government service delivery. Then, exchange information to facilitate governance innovation by expanding to include citizen, businesses, and government entities participation and open data (UN E-Government Knowledgebase, 2022). E-government as argued by Fang (2002), Aldemir and Sen (2021) advanced ICT and web applications to offer convenient access to government information and services, for enhancing service quality and promoting democratic participation, particularly in local government decision-making. E-government initiatives aim to publicize information widely through web-based applications for bidirectional communication in society and shifts in behaviors by delivery services aligned with users' exceptions (Archmann & Iglesias, 2010; Richard, 1999; Worthy, 2010).

User Experience (UX) is tied to the overall quality of user experience (Wechsung & De Moor, 2014). Usability evaluates features of technology or communication services to measure user satisfaction in meeting their needs (Möller, 2023). ISO 9241-210 defines UX as the perception of an individuals before, during, or after using a service or system, encompassing reflections on their behaviors, preferences, comfort, and emotions, alongside the efficient achievement of goals (Introduction to User Experience, 2023). Improving user acceptance for technology relies on Human-Computer Interaction (HCI) design expertise in technology utilization (Hassenzahl & Tractinsky, 2006). That aims the efficiency of information systems with focusing on the human user in digital service and technology contexts. Hassenzahl and Tractinsky (2006) emphasized the importance of addressing and mitigating user frustration, which arises from human-machine interactions to ensure success. Understanding user behavior and accessibility level of new technology from various abilities users is paramount, as it facilitates the development of enhanced interactions and acceptance (Möller, 2023; Othman et al., 2024).

2.1.2. E-government and Citizen's participation

While only 30% of countries publish citizen engagement statistics, there is a deficiency in sharing citizen input and government responses in policymaking. Despite progress in data access regulations and enforcement lags existing laws (GovTech Maturity Index, 2022). E-Government Development Index (EGDI) rankings emphasized the importance of risk mitigation and government agencies collaboration for DT success (Escobar et al., 2023; Sangolt & Keitsch, 2016). Citizen-government participation through providing multichannel communication strategy led to improve online self-service applications (Madsen & Kræmmergaard, 2016; Nielsen, 2016). Marzooqi et al. (2017) stressed citizen-centric approaches fostering technology acceptance, and autonomy across government levels influenced by user behaviors and attitudes (Cahlikova, 2017). Education and high-income level influenced technology adoption, utilization, and acceptance, serving as an indicator of technological service use (Zmud, 1979; Al-Gahtani et al., 2007; Abu-Shanab, 2011).

E-Government initiatives failed due to process prioritization over citizen needs and financial, political, and infrastructure constraints (Rammea & Grobbelaar, 2017; Tchao et al., 2017). Ineffective governance, insufficient digital skills, and strategy misalignment hinder organizations (Deist et al., 2022). Public sector transformation mandates policy/legal adjustments for evolving dynamics (Akomode et al., 2002). For e-Government success: citizen prioritization, robust privacy/security (Layne & Lee, 2001). Organizational culture shaped change success, requiring adaptations, especially in larger entities (Altameem et al., 2006). Executing strategies through defined procedures key for societal/economic benefits (Altameem et al., 2006). Also, mindsets influence DT success (Töytäri et al., 2017). E-service delivery differs impacting loyalty, consumer behavior, and satisfaction (Rowley, 2006). Lee and Lin (2005) prioritized experience to enhance trust with citizens or customers. Satisfaction is attained when online services meet users' needs and offer flexible attributes. Conversely, loyalty and satisfaction suffer from e-service failures (Wachter, 2002; Zhang & Prybutok, 2005). Web and e-government service experiences play pivotal roles in the success of DT governmental projects (Rowley, 2004).

2.1.3. Acceptance of e-services by citizens

Integrating technology enhances organizational performance. Various theories examined factors influencing digital service acceptance and engagement aiding DT. Technology Acceptance Models (TAMs), typically proposed at the organizational level, suggested users perceive digital services as useful and easy to use (Davis, 1985; Park et al., 2022). However, Venkatesh and Bala (2008) criticized TAM for overlooking societal and organizational factors affecting technology adoption then introduced Extended Technology Acceptance Model 2 (TAM2) (Venkatesh & Davis, 2008).

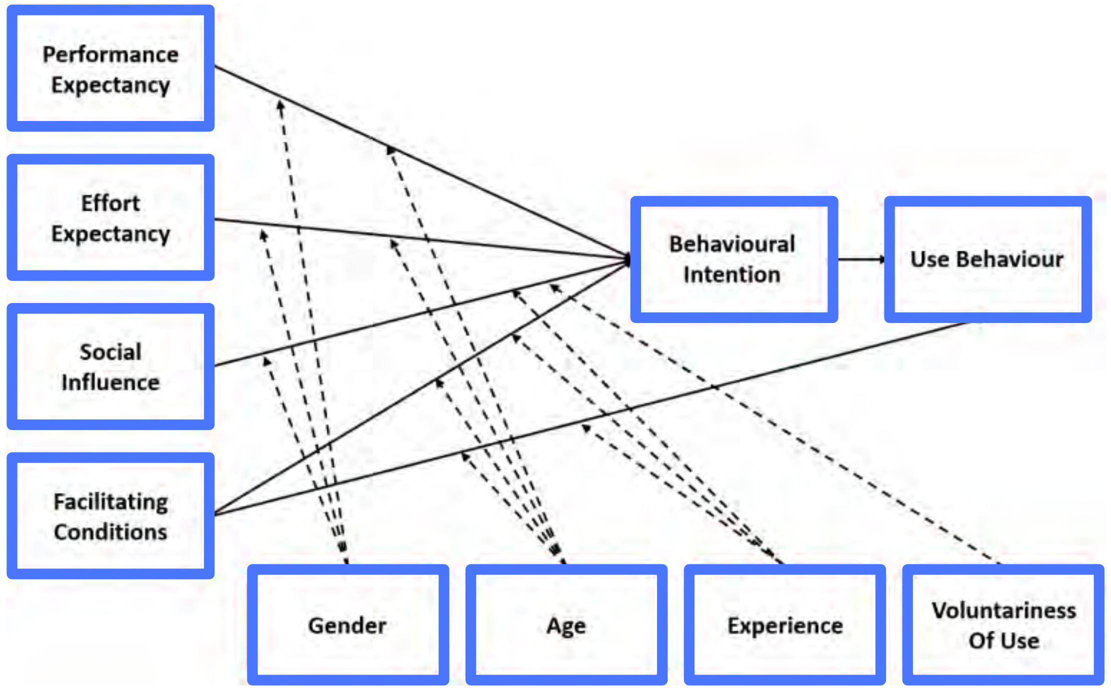

Figure 1 Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003).

Unified Theory of Acceptance and Use of Technology (UTAUT) was proposed to overcome limitations of TAM2A. UTAUT is a key model for understanding user acceptance of IT in an organization. It explains user intentions and behaviors regarding utilization of information systems and services, focusing on performance expectancy, effort expectancy, social influence, and facilitating conditions, and other moderators as age, gender, experience and voluntary control impact of four main factors (Venkatesh et al., 2003; Unified Theory of Acceptance and Use of Technology, 2023). Social influence and external factors determine the attitude and intention to use the technology. So, the users' perception might change based on gender and experience or age (Venkatesh et al., 2003; UTAUT- Innovation Acceptance Lab, 2023). That is an assessment model of its factors shape our intention which form our behavior toward usage of technology.

E-services comprise various components evaluate individually by visitors (Bauer et al., 2005). Factors like response time, download speed, security, and transaction execution influence customer technology adoption (Chung & Paynter, 2002). E-government services vary in levels, with transactional services exhibiting distinct characteristics, thus influencing UX (Gottschalk, 2009). Consequently, reassessment of e-government services is warranted (Li & Zhao, 2003). Prior studies focused on digitalization success and technology acceptance (Matt et al., 2015), overlooking UX through usage of e-service primarily. We hypothesize that the complexity of e-government services hinders individual acceptance for technology because of negatives in UX, delaying DT maturity. Just emphasizing technology and business strategies is insufficient (Hess et al., 2016); strengthening government-citizen links through contextually tailored digitally systems enhance sustainability and competitiveness (Pittaway & Montazemi, 2020).

Our study emphasizes UX challenges in main e-government platforms, with a comparative analysis of Qatar and Singapore to identify their effects in shaping technology acceptance and influencing the journey of DT. Evaluating the efficacy of these platforms requires addressing potential gaps between high expectations and user's satisfaction in Qatar. By employing UTAUT model and contrasting with Singapore that follows best digital government practices (World Bank, 2022), we discovery insights into users' adoption behavior (User Acceptance of Information Technology, 2003). Selecting both countries for approximately similar populations in 2022 (2,695,122; 5,637,022) and GDP growth rates (4.83%, 3.65%) for Qatar and Singapore, respectively (World Bank Open Data, 2022). GovTech Maturity Index (2020), Qatar ranked 10th in West Asia, the value reflects DT (Nielsen & Ali, 2021). While Singapore leads in digital government (Dener et al., 2021), ranking 7th in the E-Government Development Index in 2018 and 2nd in the Online Service Index out of 193 countries (Digital Government Ranking, 2023). Yet diverse cultural, economic, and political contexts, these digitally transforming nations offer valuable global case studies on the UX and the technology acceptance relationship through established e-government initiatives (Qatar, Singapore, 2022).

2.2. E-Government Metrics: Current Maturity in Qatar and Singapore

Governments are striving to enhance public services particularly during COVID-19 with increasing digital offerings. Incorporating global trends emphasis on customer-centric approaches to enhance citizen satisfaction (Government cx summit, 2024). Qatar and Singapore e-government strategies prioritized DT and technology acceptance for achieving national visions (Qatar Digital Transformation, 2021; Digital Government Blueprint, 2020). While Qatar focused on ICT development and e-service accessibility (TASMU's Experience Policy, 2020), Singapore prioritized collaboration for efficient public service delivery (Researchers, 2022).

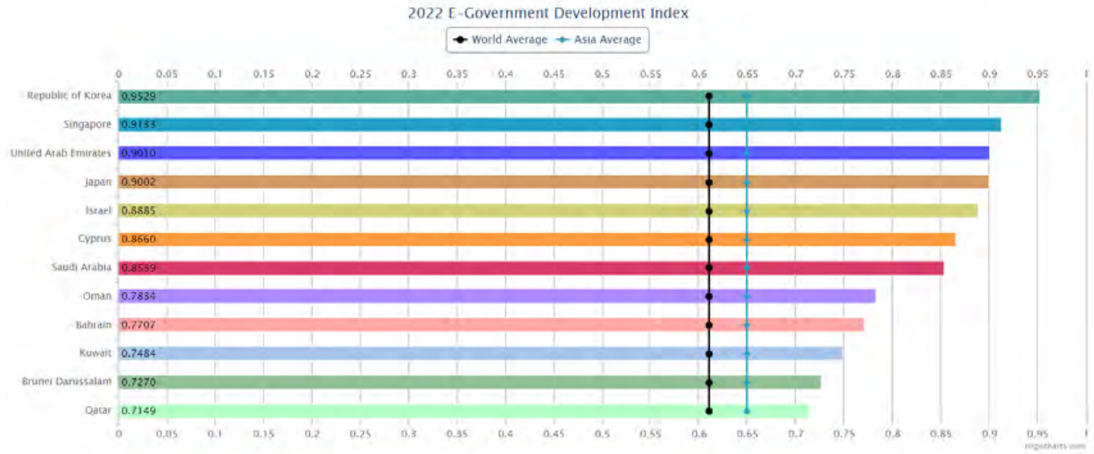

Figure 2 E-Government Development Index (EGDI) 2022 (UN, 2022).

Utilizing Customer Experience Index (CXI) assesses customer loyalty through retention and advocacy, driven by meeting needs, accessibility and emotional engagement (Gill, 2023). In 2022, UN E-Government Development Index (EGDI) ranked Qatar 78th (High) and Singapore 12th (Very High) among 193 nations to reflect governmental digitalization initiatives. Among high-income Asian nations, Qatar ranks 12th, while Singapore secures 2nd (Figure 2), Singapore's superior efficiency in delivering online services compared to Qatar (UN EGDI, 2022). Singapore surpasses Qatar regionally and globally, while Qatar trails behind UAE in Western Asia. Singapore excels in Online Service Index compared to Qatar's, both countries score highest (1) related to institutional framework; Qatar had the lowest E-Participation Index while Singapore lacking in content provision, exceled in e-service delivery and e-participation (Figure 3).

Examining Human Capital Index (HCI), Qatar scored 93.46 and 70.56 for adult literacy and gross enrollment ratio, respectively. While Singapore excelled with 97.48 and 100 for the same indicators. In the Telecommunication Infrastructure Index (TII), Singapore and Qatar reflected similarities in in mobile-cellular and active-mobile broadband but lower fixed-broadband rates and Qatar has a high number of Internet users. Globally, while citizen engagement at 0.449 prompts enhanced communication channels. Only 30 nations published data on service delivery performance amidst DT initiatives (GovTech Maturity Index, 2022; Qatar, 2022; Singapore, 2022). Government Technology Maturity Index (GTMI) reported the track of e-governments platforms performance and the progress of DT over time (GovTech Dataset, 2023). It assesses government technology maturity and pinpoints areas for improvement (GTMI, 2022).

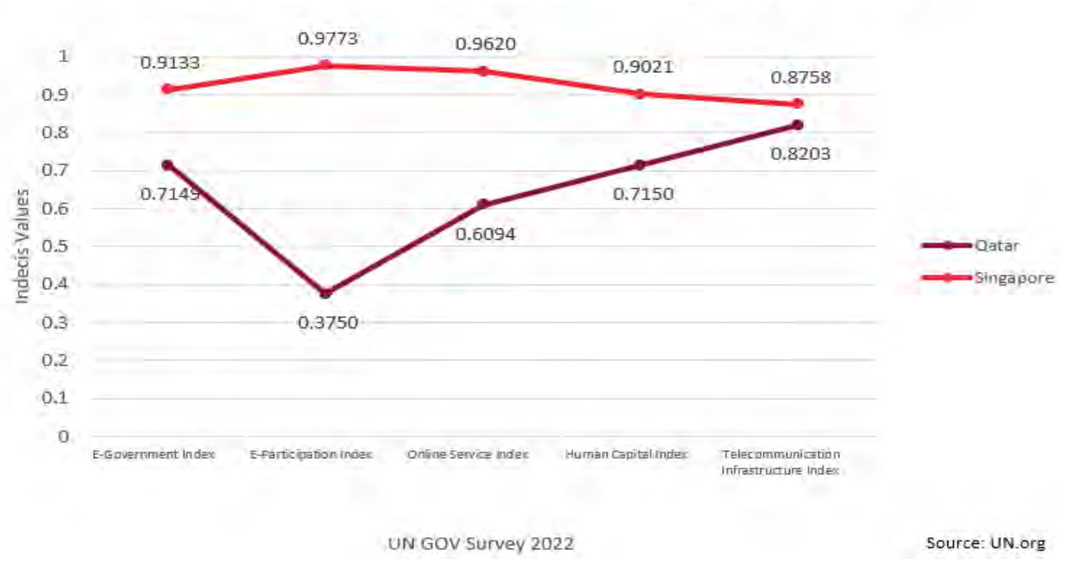

Figure 3 Comparison of Qatar-Singapore Digital Adoption Index (DAI) and sub-indices 2016 (Digital Adoption Index, 2016)

The Digital Adoption Index (DAI) focuses on the "supply-side" and availability of digital services and infrastructure over utilization. Qatar ranks 35th, while Singapore leads in 1st position among 180 countries. Upon delving into the DAI sub-indices, Singapore's government achieves the highest DAI value at 0.957, while Qatar scores the lowest at 0.604 (Figure 3). Both countries exhibit closer people-centric digital adoption values. Promoting digital adoption benefits society through business growth, improved well-being, efficient e-service delivery, and government accountability (Digital Adoption Index, 2016). Qatar aims to elevate e-service usage to 80% by bolstering trust in secure online transactions (Qatar e-Government 2020 strategy, 2020). DT efforts are aligned with Vision 2030, 50% IT adoption by 2024 and universal broadband/5G access (Qatar Digital Transformation, 2021). Hukoomi streamlines citizen-government interaction (Integrated Government Program, 2021) while challenges like awareness and security risks hinder adoption (Qatar e-Government 2020 strategy, 2020). TASMU initiatives drive smart solutions with legal frameworks, accessibility, and security measures underpinning Qatar's e-Government evolution (Government Websites, 2016; TASMU Experience Policy, 2020).

Singapore's DT prioritizes stakeholder needs through skill enhancement and adaptation (Singapore gov, 2021). The Digital Government Blueprint, accelerated by COVID-19, drives Smart Nation initiatives (Digital Government Blueprint, 2020). E-commerce and AI strategies showcase commitment to progress (Erh, 2023). Collaboration with private sectors enhances digital services for efficient transactions. UX remains crucial, with ongoing research and refinement ensuring user-centricity (crUX, 2018). However, persistent challenges in website navigation call for continuous user consultation (Researchers, 2022).

3. Limits and contribution

Recent studies emphasize technology tools creation (Abdullah et al., 2016), DT success factors include e-government initiatives, vision, ICT, education, and legitimization. While individual factors like accessibility and user-friendliness need more empirical research beyond organizational settings (Jeon et al., 2011). Despite advanced technology infrastructure, their usefulness remains debated (Park et al., 2022). Understanding previous findings' applicability in technological and social contexts is imperative. Qatar's and Singapore's Global indices reveal technical issues in the GovTech Enablers Index (GTEI) require efforts to enhance performance.

Both countries are small and share similarities but lack a thorough analysis of Singapore's advanced DT in e-government compared to Qatar, particularly in understanding IT's role as an enabler or hindrance. Consequently, the research question aims to identify Qatar e-government platform obstacles and that less advanced with Singapore's. We suppose due to absence of user-friendliness and ease of use of e-government services negatively affecting people's attitudes and behaviors toward technology acceptance. We use analysis main government platforms for both countries expose the potential maturity gap in Qatar and underscoring UX significance, especially for elders or disabled users. The assessment needs to gauge acceptability beyond organizational boundaries. User's decisions on new technology adoption are influenced by perceived usefulness and ease-of-use; simplicity promotes positive attitudes, complexities hinder acceptance (Technology Acceptance Model, 2024).

The study's objective is to underscore IT's role in fostering user-friendly interfaces and enhancing UX is crucial for practical digital service acceptance and success. Our research contributes to add insights that can improve more effective and user-friendly e-government platforms. Our findings mention the importance of ease of use, UX, and data integration from individual perspectives regarding service delivery (Park et al., 2022). Web experiences change impacts on user satisfaction, behavior, and shopping habits (Kumar et al., 2017). In addition, the research offers practical recommendations assist policy makers, designers and researchers related to refining DT projects.

4. Methodology

Aligning with the research objective of exploring UX and ease of use in e-government platforms Hukoomi in Qatar and developer in Singapore to understand their impact on technology acceptance and DT initiatives. We employ automated tools as Similarweb, Lighthouse, and ADA Site Compliance as appropriate tools. SimilarWeb provided insights into website traffic, prevalent search keywords, audience demographics, geographic location, total visits per period, engagement metrics, and comparative analysis with competing websites (SimilarWeb, 2024). Lighthouse facilitates the evaluation of website performance, compliance to best practices, usability considerations, and content maturity beside highlighting areas need to improvement (Lighthouse Report Viewer, 2024). Notably, the accessibility investigation leveraged established standards to ensure inclusivity for users with diverse abilities and disabilities, as text for images as alternative elements, color contrast and multilingual to make impact and good technology acceptance for all visitors (ADA Site Compliance, 2022).

The methodology is hypered of Quantitively analysis using website analytics and employing Qualitative Comparison Analysis (QCA) to obtain comprehensive insights from comparative multiple cases to identify various combinations of variables leading to similar results or using varying degrees of influence to generate robust findings (Ragin, 1987; Rihoux and Ragin, 2009). This approach is particularly effective for understanding how different independent variables impact outcomes (Rihoux et al., 2011). To examine main e-government platforms' content and interfaces to gain empirical insights to understand level technology acceptance based on websites' performance metrics analyzing.

Incorporating the Context, Content, Process (CCP) model proposed by Devos et al. (2007) and Kimmer (2012), our analysis simplifies cross-case comparisons. This model encompasses indicators, governance, e-Government, and impact assessment. Nielsen (2017) further underscores how each dimension, as discussed by Kimmer (2012), influences the processes, choices, and outcomes in e-service delivery. Employing this framework, we evaluate UX of governmental platforms by focusing on strengths and challenges toward technology acceptance.

The analysis of secondary data from generated reports by previous automated tools, also reputable sources including national government websites and national and international reports from UN and World Bank. Evaluation of EDGI includes sub-indicators such as e-government digital strategies, and the efficiency of public service delivery, exploring their interconnected impact (UN E-Government Development Index, 2022; Qatar, 2022; Singapore, 2022). The analysis focuses on common themes that extract based on UTAUT model like performance expectancy, ease of use and accessibility, social influence and citizen participation related to e-government services, which are crucial for successful DT initiatives and technology acceptance within the public. Also, this paper evaluates legal frameworks and policies, digital infrastructure, user experience (usability, performance, accessibility, feedback mechanisms, content quality), investments, partnerships, innovation, and data-driven decision-making to comprehensively examine e-government UX maturity in both countries.

Collecting data from different sources and using previous tools, thereby analyzed data to patterns as Nielsen (1994) usability evaluations guidelines to promptly identify and resolve usability issues. He proposed 10 heuristics for evaluating user interaction design: 1) Responsive, unsurprising system actions, 2) Logical alignment between system language and real-world usage, 3) User control over undo/redo and exit, 4) Consistency with platform standards, 5) Error prevention through informative messages, 6) Activation-based information retrieval, 7) Flexibility, 8) Minimalist task instructions, 9) Error explanation and recovery assistance, 10) Easily searchable help documentation to support users (Chatzidakis, 2022).

This paper extends beyond analysis to explore impacts, lessons, and typical approaches in e-governmental services. It highlights how prioritizing user-friendliness in e-government services during design principles. Furthermore, it addresses technological barriers, data issues, and resistance challenges to highlight what might hinder technology adoption and acceptance. Metrics and performance interpretation of both websites contribute usability and accessibility improvement recommendations. Adopting mixed methodologies and comprehensive analysis yields valuable insights into UX understanding of e-government platforms, informs policymakers and developers with practical recommendations for enhancing technology acceptance by citizens into both countries' digital governance landscapes.

5. Results and Comparative Analysis

The analysis and findings section includes a comparative study of Qatar's "Hukoomi" and Singapore's "Developer" websites, evaluating UX from the perspectives of end-users and developers (hukoomi.gov.qa., n.d.; developer.tech.gov.sg., n.d.). The evaluation process comprised automated assessments software tools such as SimilarWeb and Lighthouse to analyze key UX features (Table 1). The findings show validated the hypothesis that complexities in Qatar's e-gov platforms negatively influence technology acceptance when compared to Singapore. It indicates Singaporean website exhibits as best practices and resulting to the user centric approach with one stop platform parallel with integrity data and continues improving through user-research center. While Qatari website excelled in accessibility and heavy focusing in e-health and e-education services but struggles in fragmented data and e-services platforms that hinder technology adoption. Results are in both platforms indicate performance and effort expectancy and facilitating conditions impact users' behaviors toward e-services aligns with UTAUT, and the social influence is limited (Figure 4, Table1).

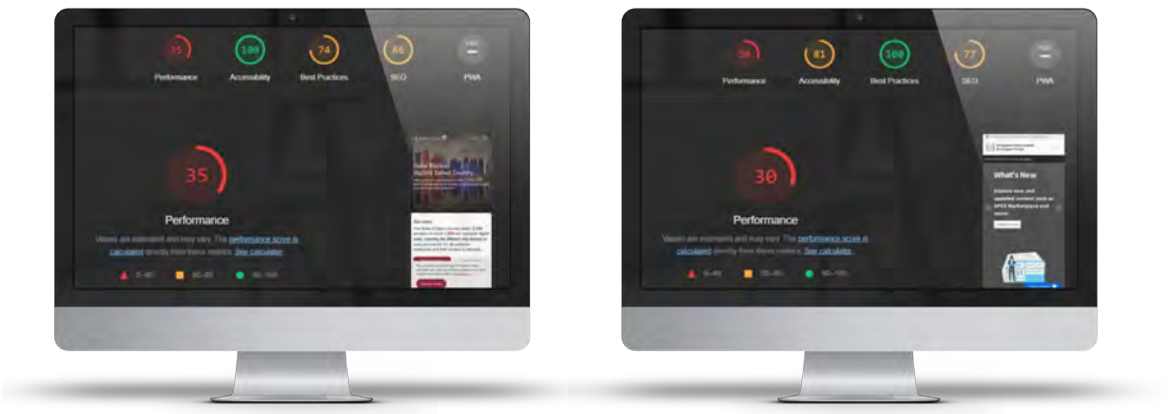

Figure 4 Comparison of Hukoomi (Qatar) and Developer (Singapore) websites using Lighthous tool, 2024 (Lighthouse Report Viewer, 2024)

Category	Qatar (hukoomi.gov.qa)	Singapore (developer.tech.gov.sg)
Performance and Usability	39%	33%
User-Centric e-services	Included	Included
Task Completion time	Found information with error message	Found information with filtering options
Accessibility	Color contrast ensures readability, multilingual support, keyboard navigation, enabled screen reader, zooming-in and out (100% score)	Screen reader compatibility, links based on color who have low vision, (81% score)
Interface Design	Clear and consistent design, easy to use across devices, serves diverse population	Modern, user-friendly design, mobile responsive
Content comprehensiveness	Wide range of services, open government initiatives, interactive tools	One-stop shop, comprehensive information, transparency & accountability, interactive elements
Searchability	Efficient search engine	Efficient search engine
Information Hierarchy	Clear navigation and easy access to content	Information organized and structured logically
Content Quality & Readability	Addresses user needs, accurate and clear content	Addresses user needs, accurate, clear, and well-formatted content
Transparency & Accountability	Needs further investigation, open data initiatives, engagement platforms	Feedback mechanisms, open data initiatives, engagement platforms
Interactive Features	Limited, recently	Diverse feedback mechanisms, engagement platforms
Engagement	Encouraged feedback and suggestions	Encouraged feedback and suggestions, promotes open data and citizen involvement
Satisfaction	High time on page, high click-through rate	High time on page, high click-through rate indication of satisfaction
Users direct feedback	Utilizing Shark platform, alongside online surveys, polls, and forums	Gathering qualitative data on pain points and preferences

Website Traffic Demographics & interests	Most users: 35-44 years old, male & Browsing: Finance > financial planning, management, google, social media, gov	Most users: 25-34 years old, male & Browsing: Computers Electronics and Technology > Programming, developer Software, google, social media, government
Competitor's websites	mol.gov.qa, moci.gov.qa, nas.gov.qa	mycareersfuture.gov.sg, opencerts.io, smartnation.gov.sg
Top keywords	Health card renewal, تجديد البطاقة الصحية قطر	no data
Traffic from social platforms	Most from WhatsApp webapp then reddit	Most from Linkedin, Meetup
Web-to-web links	No data	To 10 websites, 50% government, education, technology
Properly size images	Not properly, inefficient video format for animated content	Hidden images
best practices	74%	100%
Compliance	45%	52%

Table 1 UX Comparison: Governmental Websites (Qatar, Singapore) (ADA Site Compliance, 2022; hukoomi.gov.qa., 2024; developer.tech.gov.sg., 2024; Lighthouse Report Viewer, 2024; Similar Web, 2024; Participate | Sharek, 2024).

5.1 User Experience in GovTech (Performance and Effort Expectancy)

UX factors in e-government services included time and effort savings, convenience, usability facilitation, transparency and accountability, trustworthiness, and engagement influencing citizen and user behaviors (Table 1) (GovTech Maturity Index, 2022). Conversely, delays in response, service unavailability, outdated information, and transaction failures result in dissatisfaction and necessitate service delivery re-evaluation. Both countries exhibit variations in UX, particularly in website performance and ease of use (hukoomi.gov.qa., 2024; developer.tech.gov.sg., 2024). Moreover, improved acceptance stems from perceived usefulness (Davis et al., 1989). Both countries are committed to accessibility and usability as legal requirements where Qatar advanced, such as screen readers of web pages content for all text and images' alternative text and video text to deliver messages, AI generation text is not used because it is inaccurate and based on human text (Table 1). That aligns with American Disabilities Act (ADA) (2022) outlines accessibility standards to ensure inclusivity and equal access.

Hybrid CX in Hookumi and developer are blending online and human interaction, influences customer loyalty significantly, there is various customer contact channels such as mobile apps, 24/7 phone lines, and chatbots, additionally to human representatives remain crucial for problem resolution to enhance CX quality (Gill, 2023; hukoomi.gov.qa., 2024; developer.tech.gov.sg., 2024). High satisfaction found on both platforms, indicated by high time on page and click-through rates relevance to digital engagement (Table 1) (Lighthouse Report Viewer, 2024). User satisfaction is crucial for e-government service adoption impacting UX, while failures negatively impact it (Seo et al., 2018) aligns with usability definitions encompassing accessibility, operability, user-friendly, and error prevention for effectiveness and satisfaction (ISO 25023, 2016; Sharabati et al., 2015). The monitoring improved the alignment of data-driven services with user needs. Average performance and usability with low in them indicate unused navigation features and unexclusive information (Table 1) (Van Staden et al., 2015).

The availability and maturity of e-services in Singapore depended on the interaction between public and government, delivering public services through unified "one-stop" online platforms (developer.tech.gov.sg., 2024), Singpass is a mobile app that citizens use for over a thousand government services, including online social services, document processing, and identification (Singapore gov, 2021) and GeBiz Singapore's central tender platform aids businesses that provide public services, enhancing efficiency and convenience (Curtin et al., 2003, p. 26). Two applications enhance knowledge sharing between institutions, and improving the efficiency of operations based on usefulness reviews (Curtin et al., 2003, p. 23). Qatar offered a diverse selection of services but not as "one-stop" platform (hukoomi.gov.qa., 2024), the use of distributed ICT management hinders interoperability, increases integration complexities, and hinder service delivery (Curtin et al., 2003, p. 26).

In Singapore, UX Researchers (USER) is an agency with consulting experts guide national and global organizations to enhance UX, making it simple, comfortable, and highly accessible. Well-designed websites contribute to better website performance, providing competitive advantages in all services (Researchers, 2022). This improvement benefits, fosters good governance and builds a positive reputation. Apps share info and aid communication in government services like banking and healthcare. Financial services rank highest in CX compared to sectors, with a strong emphasis on security, they prioritize quick, simple, and customer-focused delivery, fostering loyalty and advocacy (Customer Experience Excellence Report Singapore Summary, 2019). Qatar has invested in technology initiatives like e-Health and e-Learning through financial investments and institutional e-government reforms (Faisal & Talib, 2015). However, these initiatives faced adoption challenges (Al-Shafi & Weerakkody, 2008), underscoring the importance of optimizing UX for successful implementation.

5.2 Social Influence and citizen participation

Qatar utilized Shark platform, alongside online surveys, polls, and forums, while Singapore gathered qualitative data on pain points and preferences (hukoomi.gov.qa., 2024; developer.tech.gov.sg., 2024). Advancing citizen-centric services mirrors leading GovTech nations' advancement, requiring attention to cultural norms and digital literacy to overcome access barriers (GovTech Maturity Index, 2022). E-participation and e-feedback is pivotal for evaluating digital citizen engagement, employing national platforms for engagement of citizens to policy decision-making, with government responses published. Governments gather user requests and suggestions, enhancing CivicTech through modern technology like chatbots and forums. However, satisfaction levels vary due to demographic disparities, with Singapore showing greater compliance standards (Table 1).

5.3 Facilitating Conditions

Qatar and Singapore as Group A countries enhance GovTech maturity by aligning units with the Prime Minister's Office, promoting government-wide approaches and efficient solutions, monitoring compliance, and enhancing government transparency through public data publication and policy discussions but adoption as forums which are limited (GovTech Maturity Index, 2022). Establishing a comprehensive technical framework of policies across government agencies for unified ICT system design and management across agencies to enhance efficiency and encourage reuse of components (Curtin et al., 2003, p. 26). Government agencies utilize cloud platforms for secure access to public services, but they lack user-centric design. Mobile access is expanding, driving demand for integrated online platforms to deliver streamlined (GovTech Maturity Index, 2022). Slow institutionalization due to resource allocation, coordination, and data management issues (GovTech Maturity Index, 2022). Both governments build public employee capacities, collaborate with academic institutions (Table 1). The national strategies prioritize innovation DT initiatives and policies supporting startups and fostering digital skills (GovTech

Maturity Index, 2022). Yet Qatar lacks a policy for e-participation, on the other hand Singapore employs Government Response Mechanism (GRM) for public feedback on service delivery, fostering transparency and responsiveness. Despite Qatar's availability of reports, data on government responsiveness to citizen feedback and service updates remain absent, revealing a disparity between the two countries (GovTech Maturity Index, 2022; Govtech Dataset | Data Catalog, 2023).

5.4 Lessons from UX Singaporean Experiment

ICT training targets diverse age groups and computer skill levels to enhance employability and digital literacy, including Internet skills until development technology (Curtin et al., 2003, p. 25). Human capital capabilities, a clear strategy and a strong ICT infrastructure led to successful e-government initiatives and adapting to change to serve the public, through automation, coordination, then change in the social, technological and commercial areas (Curtin et al., 2003, p. 21). Implementing an Action Plan focused on; reviewing policies to integrate systems for customer-centric e-services, improving responsiveness, and fostering innovation through experimentation to create new values for government and citizens (Curtin et al., 2003, p. 22). Digital service maturity hinges on robust leadership, sponsorship, user-centric, and governance for sustainable development (Curtin et al., 2003, p. 26).

6. Discussion

The paper is based on the strong theoretical framework of the Unified Theory of Acceptance and Use of Technology (UTAUT) model, focusing on user IT acceptance and the impact on DT journey. It explains intentions and behaviors of users regarding the usage of information systems from various perspectives, including performance expectancy, effort expectancy, social influence, and facilitating conditions addition to moderators such as age, gender, experience, and voluntariness (Venkatesh et al., 2003). The study's results aligned with UTAUT, where performance expectancy impacted users' perceptions toward the benefits of e-government platforms. Effort expectancy, the ease of use of e-government platforms and clear content impacted user perceptions then increasing interactivity. Innovation Diffusion and Technology Acceptance theories' emphasis on simplicity fostering positive IT attitudes, while complexity hinders adoption (Park et al., 2022). The outcomes of a usability assessment on both platforms are consistent with Nielsen's heuristics (1994) factors, that help to evaluate pinpointing areas and implement them lead to tangible improvements in assessing online websites or services.

Social factors are available in different, such as participation from individuals, influenced users' attitudes and behaviors toward using e-government services. Facilitating conditions represented supportive factors or obstacles from the external environment, such as digital skills for individuals, Internet broadband and technical support are found in both countries as initiatives, that affecting users' acceptance of digital government platforms. Controlled variables, demographic factors like age and gender might influence users' behaviors toward the usage of e-services. The study found that most visitors were males aged 30-45 and 25-34 in Qatar and Singapore, respectively, which could impact perceived usefulness and behavioral intentions.

The study's results show both countries prioritize citizen satisfaction, facilitating transactions-level, and e-participation initiatives (GovTech Maturity Index, 2022). Singapore leverages strong e-participation to refine user-centric e-services based on feedback. Developer platform excels in best practice and user-centricity. While Hukoomi emphasizes accessibility with fragmented data. Singapore offers a "one-stop" shop, high-quality data and published, and robust engagement mechanisms. This observation underpins our hypothesis suggested a lower level of UX impacts technology acceptance among citizens in Qatar compared to Singapore.

Our research contributes theoretically to understanding user technology acceptance of e-government platforms. Analyzing the UTAUT model, Performance and effort expectancy are key factors shaping attitudes and usage behaviors. Demographic segments such as age and gender showed a moderating effect, even if it was less significant. Our study underscores the importance of UX design, as understanding user contexts enhances satisfaction, loyalty and fosters positive usage behaviors and acceptance, ultimately increasing the value of e-government platforms. By illustrating user interactions, we extend the theoretical foundations of UTAUT, providing insights into the drivers of technology acceptance for e-government and DT.

The findings have practical implications for policymakers, designers, and practitioners in e-government. Addressing weaknesses retains users whereas successful products refine not reinvent. User-centric design and user involvement strategies should be prioritized when developing e-government platforms to increase user technology acceptance, often by refining existing solutions. Agile methodology adoption is favored for its adaptability and iterative enhancement of customer satisfaction. Thus, iterative improvements in UX embraces diversity ensures everyone has a unique and satisfying interaction to achieve inclusiveness across diverse users with varied expectations, experiences, abilities and provision continuous feedback channels can enhance perceived ease of use, perceived usefulness, and user participation.
The insights contribute to decision-makers' ability to make policies based on baseline analyses of e-government services pain points of users during their use to lead to user-friendly interfaces (What Is Usability Evaluation?, 2023).Achieving accessibility for disabilities users through features like user testing with diverse individuals. That might be overlooked, refining based on their feedback ensures more inclusive design (UX Design, 2024). UX Guidelines there's no Arabic version available in Qatar. Another issue is the absence of governmental forums that could facilitate and publish government-citizens' responsiveness, making it unclear how updates are made based on citizens' feedback. Understanding the audience, ensuring simplicity in design, and meeting expectations are crucial. Team with multilingual skills or cultural consultations help bridge language gaps and understand diverse expectations (UX Design, 2024).

Embracing ICT, optimizing usability and enabling citizen participation via digital channels foster transparency, user satisfaction, and inclusive policymaking by impartially processing requests (Bertot et al., 2012). Enhancing the usability of e-government services cultivates positive UX, corroborating prior research findings (Shareef et al., 2011). Furthermore, citizen engagement through online platforms is highly valued, and incorporating social media facilitates public feedback on policy issues (Bertot et al., 2012; Kumar et al., 2017). The robust Internet connectivity in both countries ensures access to up-to-date government information, with service convenience enhancing citizen attitudes (Bhattacherjee, 2001). Website accuracy was advanced in Singapore side that is crucial for citizen engagement (Cullen & Houghton, 2000). Citizens prioritize e-government services over traditional methods due to ease, speed, and convenience, driving behavioral changes and time-saving benefits (Gilbert et al., 2004; Curran & Meuter, 2005). Consequently, reliable connectivity, accurate information, and user-centric service design foster positive citizen attitudes and adoption of e-government platforms. Government services are distinguished using technology and data, but societal challenges such as data privacy persist. Web Summit enhanced awareness, tackled CX digitalization in global governmental agencies, involved stakeholders, and provided customized solutions for both private and public entities (Governmentcxsummit.Com, n.d.). Achieving GovTech maturity entails investment in e-government enablers and income generation (GovTech Maturity Index, 2022).

While our research has certain limitations, such as the inability of using Google Analytics and challenges in establishing causal relationships between variables, it primarily focused on user behaviors, overlooking influential factors like cultural and social differences, addressing limitations of users and the system is essential for systems' designers, not just addressing as human error on both sides (What Is Usability Evaluation?, 2023).

Future studies could explore technological acceptance dynamics in e-government services through experimental data, particularly in sectors like education or healthcare. Employing tree testing and usability evaluations could measure the effectiveness of navigation systems, while quantitative metrics might capture user complaints and qualitative data could reveal emotions and initial impressions. Our study's geographical confinement may restrict the findings' generalizability, urging subsequent research to extent diverse platforms and institutional contexts, thereby enriching our understanding of technology acceptance in e-gov services' DT.

7. Conclusion

In conclusion, this study using the extended UTAUT model aims to evaluate the impact of UX on user technology acceptance and maturity of DT in e-gov platforms to understand obstacles make Qatar lags Singapore. The results indicate Performance and effort expectancy are similar for both platforms shaping user behavior toward technology use. Furthermore, facilitating conditions like Internet broadband and technical support play a role in DT initiatives. Social influence does not appear well but a notable observation most of users are male. Qatar excels in accessibility, invested in e-health and e-education services but struggles with challenges in adoption, data fragmentation, and comprehensive e-services availability. Meanwhile, Singapore showcases best practices through owns "one-stop" platform, e-financial services achieve high CX, and data integration.

This study encountered several limitations; primarily much of data related to Qatar was unavailable for public access, and inconsistencies were noted in the information available, leading to ambiguity regarding accuracy. So, Qatar needs centralized platforms for consistent, up-to-date data through inter-agency collaboration, ensuring robust data governance and investment in a data-driven culture (GovTech Maturity Index, 2022), addition to standardized reporting and adopting best practices from Singapore as usage APIs and establishing a research center focused on user-centric challenges could foster effective and efficient solutions to follow Singapore experiment. Time constraints posed challenges in conducting interviews and surveys, particularly for applications in Singapore. Consequently, the analysis relied just on automated methods to investigate UX on the main websites of both countries. As a result, the UTAUT framework requires further data collection to yield comprehensive insights. In addition to lack of real user perceptions from each country, socio-cultural and demographic factors were not considered to measure their direct effect.

The study recommends both countries to establish e-participation multi-channels to address issues encountered by users' journey on e-government platforms, and the government responds to the evolving needs and changes of citizens, with a focus on accessibility and ease of use for e-services. E-service portals require enhanced DT policies from individuals and businesses view to improve user-friendliness and accessibility for disabled individuals to highlight surfing issues, plan for long-term improvements, and build citizen skills then assessment human capital evaluates ability to use e-services (E-GDI, 2012). That collaboration is between Qatar's Mada center and Singapore's Infocomm Media Development Authority (IMAD) and Disabled Peoples's Association (dpa) then supported by policy makers (Yazid, 2024). The collaboration between academic institutions, government agencies, and digital entrepreneurs and businesses is needed to enhance UX and adherence to unified technical standards should be mandated (Enhancing User-Friendliness, 2023). Use AI to evaluate usability to uncover opportunities and trends but we need human effort to mitigate the bias of AI (What Is Usability Evaluation?, 2023).

Future research CRM research focuses on understanding user behavior and developing tailored solutions to meet their needs effectively (Curtin et al., 2003, p. 29). Investing in secure e-services might promote resilience. Addressing the digital divide and its impact on public-government trust, in addition the existence accountability and transparency might enhance GovTech initiatives' maturity (AlTurky et al., 2021). Digital culture might encourage the mindset shift within society toward technology acceptance. The interaction between the two nations could create better opportunities for improving the usage of e-government services and sharing best practices. Ultimately, Qatar could learn from Singapore's best practices on how to enhance platforms and improve UX by adhering to compliance standards. Singapore could incorporate accessibility improvements based on Qatar's experimentation in this area. By fostering a collaborative environment, both countries can benefit from shared knowledge and experiences, driving the advancement of user-centric e-government services. More, this field could study public policies and guidelines related to UX of online services, or exploring the impact of cultural and social factors on user motivation in these countries, as Baazeem (2019) highlighted user backgrounds influenced technology choices. Incorporating user participation and contextual factors would enhance the understanding of technology acceptance and e-government service adoption.

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Digital Accessibility and Assistive Technology for Autism Spectrum Disorder in Dental Setting:

Interactive Communication, Treatment, Referral, and Follow-Up

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Abstract: This paper aims to highlight the connection between oral health and ASD and aims to make dental care more accessible for autistic people. It was proven by multiple studies that autistic individuals are more prone to dental problems, yet they are less likely to seek dental care, and when they do, there are often gaps that prevent them from getting proper care. It is important to address the issues ASD individuals face in order to provide better oral care and improve oral health and awareness in the individuals, parents, and caretakers.

1. Introduction

Autism Spectrum disorder (ASD) is defined according to the Fifth Edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-5) as the complicated neurodevelopmental disorder characterized by:

- **Continuous difficulties with social interactions and communication.**
- **Interests, activities, and behaviors that are limited, restricted, and repetitive.**
- **Day to day life is affected by the symptoms.**

The word "spectrum" describes the variation and severity of the symptoms experienced by different individuals. Some autistic individuals experience very mild symptoms which cause them to be diagnosed later in life and in some cases never diagnosed. In recent years, the number of children diagnosed with autism has risen to reach a prevalence of 1 in 54 children, this is according to a paper published in 2020 by Como DH. et al. Como DH. et al. pointed to the fact that autism used to be rare, but numbers of diagnoses have increased significantly in the last half century. Dentists must be alerted to this major surge in ASD diagnoses, because nowadays they are more likely to encounter autistic individuals in their practice. Autism impacts various areas when considering overall health, which in turn affects oral health as well.

This paper will highlight how oral health and autism are related and propose solutions to bridge the gap between ASD individuals and receiving proper dental care.

2. Methodology

The study employs a qualitative approach, using a combination of literature review and analysis of case studies to explore existing challenges faced by individuals with ASD in dental settings and identify opportunities to enhance accessibility through digital tools and assistive technologies.

Limitations include the reliance on secondary data which may introduce bias to this paper, in addition to the limited technologies that are currently implemented in dental setting for ASD individuals.

3. Discussion

3.1. Association between dental health and autism

In this section, a brief description of some issues individuals with ASD experience and are related to oral and dental health will be mentioned.

- **Sensory Processing Disorder:** Sensory processing disorders are sensory modulation issues in which the affected person does not respond appropriately to a stimulus. People affected by sensory processing disorders can struggle with over- or under- responsiveness to a stimulus, which can result in poor coordination, seeking sensory stimulation, or avoiding sensory stimulation.

  TVisual and auditory stimuli at the dental office can be unbearable for individuals with ASD. This leads to individuals with ASD avoiding dental visits which leads to escalation of the issue and needing more invasive procedures, often, they get referred for conscious sedation or general anesthesia (which is more expensive) for procedures that are usually treated by simple local anesthesia.

  It has been suggested in a study by Cermak et al. that dental treatments carried out for children with autism in a sensory-adapted dental environment were more effective that treatments carried out in regular dental environment. In 2015, a review carried out by Nelson et al. suggested that children with autism are less likely to be triggered by sensory input when the environment is familiar.

  Another aspect of sensory processing disorders and autism is sensory over-responsivity during toothbrushing. A cross-sectional observational study was conducted in 2020 by Khrautieo et al. that suggested that individuals with ASD are less cooperative when it comes to toothbrushing, especially at the dental office. This leads to an increased risk of dental caries and tooth loss. A study done by Jaber M. also found that autistic individuals have poorer oral hygiene and an increased caries risk. In conclusion, individuals with ASD struggle to get dental treatment due to sensory processing disorders and negative sensory input during dental visits, and to minimize this, the dental environment should be familiar to them. In addition to that, they have an increased caries risk due to sensory over-responsivity during tooth brushing which makes them perform oral hygiene measures poorly.

- **Avoidant/ Restrictive Food Intake Disorder (ARFID) Associated with ASD:** Avoidant Restrictive Food Intake Disorder (ARFID) is defined as a feeding and eating disorder in which the individual lack interest in eating and avoid food due to sensory characteristics (taste, smell, texture, etc.) or out of fear of the negative reaction of eating. Some consequences include weight loss, failure of children to meet weight milestones, nutritional deficiencies, depending on supplements and/or enteral feeding, disruption with psychosocial functioning.

It has been estimated that ARFID and ASD co-occur in 12.5%- 33.3% of cases in a study done by Kozak A. and published in 2023. One of the many complications of ARFID is gastroesophageal reflux and vomiting. Acidic substances cause the pH level of the oral environment to drop significantly which cause erosion, this is a type of tooth surface and enamel loss due to acid attacks. Another manifestation of acid attacks is soft tissue symptoms like burning and sensitivity.

Ehlers-Danlos syndromes (EDS) and its' relationship with autism and dental health: Ehlers-Danlos Syndromes (EDS) are a group of hereditary connective tissue disorders that affect collagen and extracellular matrix synthesis and maintenance. Individuals with EDS have marked skin fragility and hyperextensibility, hypermobile joints, and tendency of bruising.

EDS impacts many areas of the body; however, the focus here will be on the orofacial area. Before detailing how EDS affects oral health, it is necessary to mention the role of collagen and how vital it is to maintain the overall health of the teeth and periodontium. In teeth, the collagen forms a matrix for the mineralization of mineral platelets in dentin where it is the major component, so it provides a scaffold for mineralized tissue formation. When compared to enamel, which is the outer layer of the tooth, the dentin underlaying is less mineralized and less brittle, it can withstand high compressive forces and masticatory load due to the abundance of collage. Therefore, any tooth with dentin abnormality is a weak tooth that fractures easily even under masticatory forces.
The teeth are supported and held into their place by the periodontal ligaments which are bundles of collagen fibers. They can withstand masticatory forces and heavy occlusal loads. An easy analogy to that would be a trampoline, as a person jumps on it, the frame and jumping mats do not break as they are held firmly by flexible springs that can slightly extend and redistribute forces, and any issue with these springs will affect the strength the trampoline can tolerate, and in severe cases it will make the components detach from each other.

- **Negligence and disregard of oral hygiene:** A descriptive cross-sectional study was conducted in Chennai and published in 2022 by Suresh S. et al. showed increased instances of poor oral hygiene among disabled individuals due to negligence by parents, caretakers, and even dentists. People with mild instances of autism are capable of maintaining good oral hygiene, while others are unable to do that, therefore, they rely on caretakers or parents to assist them in performing oral hygiene measures. The level of functioning of autistic individuals and performance of oral hygiene were correlated according to a survey done by Weil TN et al.

The level of cooperation in ASD individuals correlated strongly with how severe autism is, and the level of functioning such as talking, listening, ability to perform self-care, etc. of each individual, as people who have more ability to speak, listen, and converse showed better ability to perform oral hygiene practice independently, while autistic individuals with lower functioning abilities struggle to do so, and their caretakers must assist them to brush and floss their teeth. Sometimes, caretakers struggle to do so due to decreased cooperation or sensory issues so many of them give up on oral hygiene. Challenges individuals with ASD face at the dental clinic:

It has been highlighted that autistic people suffer from various oral implications, so it is logical that special care should be available for them. Unfortunately, many of their needs remain unmet.

3.2. Inexperienced dentists:

Special care dentistry (SCD) is a part of dentistry that focus on providing treatments for people with disabilities and preventing the emergence or progression of dental diseases. Early recognition and prevention of disease is a big part of SCD. Another part of SCD includes providing care for people with complex additional needs.

The lack of special needs dentistry curricula in dental colleges and schools has been recently demonstrated in a study published in 2024 by Scepanovic T. et al. This study is one of its kind as it was carried out globally in 1265 dental schools across 180 countries. The results were astonishing and concluded that there is a lack in dental schools curricula that focus on providing care for people with disabilities even among the G7 countries which are considered the world's most economically advanced countries.

The study also pointed out that knowledge and education regarding SCD and providing dental care for disabled people should be crucial for both general and specialized dentists.

General and specialized dentists must be well versed in SCD so they can provide preventive care and perform minimally invasive procedures for patients with mild to moderate autism who have the potential for being cooperative instead of referrals and extra costs for the individual.

3.3 Inaccessible dental clinics

Inaccessibility in dental clinics for individuals with ASD is a multifactorial issue as suggested by Parry JA. et al. some of the issues will be discussed in this section.

- **Dental anxiety and phobia:** In an article published by Beaton L. et al. about why people are afraid of the dentist many reasons were explored. Traumatic experiences, learning about bad experiences of other people, and individual personality traits were all reasons to cause dental phobia and/or anxiety. It has been suggested that 50% of those who have dental fear and anxiety acquired it during childhood, and it persisted with them into adulthood. Analysis showed that the number of tooth extractions a child had had is correlated with higher incidents of dental fear and anxiety. It is also important to point out that children reported lower levels of dental fear if they had had more check-up visits before receiving treatments. Studies conducted in the UK showed that people with ASD experience higher anxiety and fear related to dentists compared to other people.
  This anxiety does not only come from the individual, but also from the dentist, Parry JA et al. mentioned that dentists feel anxious when treating people with autism. Autistic individuals have difficulties when engaging with the dental team due to their anxiety and fear, so challenging behaviors are not uncommon for autistic children. Dentists often find it difficult to deal with these behaviors from neurotypical children, so it is understandable that dealing with autistic patients can often times be challenging. Parry JA et al. also highlighted that many autistic individuals get dental treatments under general anesthesia and suggested that more practical primary dental care strategies must be implemented and considered.

  Dentists are often very well trained to deal with situations like screaming, crying and decreased cooperation from patients, they use many methods to reassure the patient and provide a more comforting environment.

- **Sensory sensitivity:** As discussed above, people with autism struggle with sensory processing disorders, and this is one issue that causes extreme distress for them when getting dental treatment. Unfortunately, many dental clinics lack the facilities to help autistic people deal with the issue of increased sensory sensitivity despite the inherent nature of dental clinics to be increasingly stimulating.

  One example of that is sensory distress caused by the texture of a material or an item. Parry JA et al. collected data about experiences of autistic individuals at the dentists, parents of one autistic individual reported that their child would accept treatment and is usually laid back, however, the child panics, cries, and sweats when the material used for cleaning is mentioned that it would be used on him, because according to them it feels gritty.

  Another aspect of sensory sensitivity is associated with visual stimulation. Lights and reflections during dental treatment could pose an issue with individuals with autism. Auditory stimulation also causes increased sensory overload for autistic people. At the dental office the sounds of machines running, clocks, handpieces, suctions, etc. are all difficult to tolerate and cope with.

  Other stimulations that are difficult for individuals with ASD to tolerate include taste, vibrations, and even the dental team touching them.

- **Difficulties in communication:** Vogindroukas I. et al. published a study in 2022 titled "Language and Speech Characteristics in Autism", in which they emphasized that both written and oral linguistic abilities are different for different individuals with ASD. Some of them demonstrated poor linguistic ability while others showed above average ability. The challenge with communication with the dentist is clearly found in the first group where their limited ability to express written and verbal language prevents them from explaining their symptoms clearly to the dentist. For some people, they can communicate with some assistance.

  In addition, ASD individuals can be verbal, minimally verbal, or non-verbal. It is the dentist's duty to recognize the communication pattern for each person and communicate accordingly in a way that suits their needs and makes it less challenging for them.

- **Challenging behaviors:** Edelson SM. Mentioned that many people on the spectrum are reported to have challenging behaviors that include hostility and aggression towards people like hitting, biting, or scratching, self-harm like pulling their hair, biting their hands, or slapping themselves, and severe tantrums.

  It has been stated since the 1960s that challenging behaviors fall under a paradigm that starts with receiving stimuli that provokes the challenging behavior and depending on how the behavior is reinforced whether negatively or positively the recurrence rate and severity of the same behavior will be less or more likely to re-occur. This is known as operant conditioning paradigm.

  Bijou and Baer contributed to this by publishing their research and theories regarding human and child psychology and children development. Their work was referenced in Edelson SM. Article as contributory to the operant conditioning paradigm as they have modified it to include an individual's internal factors such as physical pain, discomfort, and fatigue, and their external surrounding like light and temperature, and categorized them as setting events. In this case, the flow |of events preceding the occurrence of undesired behavior will include internal and external factors.

  How an autistic individual display behavior also depends on their interoception. Interoception is internal body sensations that include hunger, thirst, pain, bowel movements etc. interoception is mediated by parts of the brain and studies have demonstrated that individuals with ASD interoception is poorly regulated. Some people with autism display an increased response while others displayed lower response due to dysregulated interoception.

  Interoception comes into play in the display of negative behavior, as high interoception, over-responsiveness, and inability to locate pain and discomfort were all correlated to increased display of undesired behaviors severity and frequency.

  Dentists are aware of the concept of negative and positive reinforcement, so they should always make sure to apply these concepts accordingly and in the correct manner all while taking into account the person's nature, setting factors, interoception, and pattern of challenging behavior.

Those were some of the factors that explain why many autistic people struggle with maintaining their oral health which stems from (but not solely) dental clinics lack accessibility for individuals with ASD. Some important points include: inexperienced dentists who have little to no knowledge and experience when dealing with people with autism and lack of dentists who specialize in SCD, the inherent nature of autistic individuals to be sensory- sensitive and the nature of dental clinics to be sensory-stimulating, increased levels of anxiety and phobias that can make communication difficult and result in undesirable behaviors that dentists find difficult to control, and intellectual disability that also affects effective communication.

3.4. How to make dental care more accessible for individuals with autism?

In this section, suggestions will be discussed to make dental care more accessible for autistic individuals.

- **Modification of the environment at dental clinics:** When it comes to taking in sensory input for ASD individuals, it starts right from entering the clinic. Dentists usually start observing the patient right from that moment too, because the moments the patient walks in can give so much information regarding their personality and behavior. Autistic individuals can behave in any of these ways depending on the severity of their autism, setting factors, interoception, and many other factors. The role of the dental team is to be welcoming of the individual from the moment they walk into the clinic. The team should introduce themselves, explain their roles, and the dentist must explain what they will be doing today. This simple gesture could have a significant impact on the autistic person because each time the dental team welcome them and introduce themselves it gives them a sense of familiarity. Next, the dentist observes their patients in the waiting room, because that too can give a clear idea about the person. Autistic individuals behave differently in the waiting room depending on the aforementioned factors. What dental clinics can do to make autistic people dental visits easier is not to let them wait for a long time and to make the environment in the waiting area more comfortable for them.

As previously mentioned, individuals with ASD struggle with sensory issues that can be triggered by light and sounds. It is preferable if the waiting area has dim lights, it is also preferable that treatment rooms doors remain closed so loud sounds do not reach the waiting room. The waiting room must not have any kind of strong smell or fragrance.

Another way to modify waiting areas is to provide a sensory area that has colors, books, cubes, toys, etc. and to provide comfortable chairs. The surfaces should be soft, and lights should be dim. Soft mats and interactive sensory toys or gadgets can also be used.

It is important that the environment is also comfortable for them. Some dental materials contain very strong smells like eugenol or sodium hypochlorite, so the room should be well ventilated or other fragrances that the autistic person prefer can be used to mask the strong scents. It is also crucial that the environment is familiar for the autistic person, so what the dental team can do is arrange for the individual to visit their clinic for a few times while introducing them to the place, let them explore the dental chair, suction, masks, and tools. These visits main aim is to familiarize the autistic individual with the environment, not to provide treatment. In addition to that, these visits are also important for the dentist as they give them an idea about the individual's personality, pattern of behavior, and degree of cooperation.

One of the best ways to deal with anxious patients of all ages is the show, tell, do, technique that all dentists are aware of. One way of implementing it is to show the person the suction or saliva ejector for example, then explaining that this tool suctions the water and saliva from the mouth, a dentist can then proceed to put some water in a cup and suction it and telling them that this is how it works, finally they can try it in their mouths.

Another way of improving the treatment experience and outcomes is to have distractions for the autistic person. A screen can be attached to the dental chair with the remote being with the person. Noise cancelling headphones can be used as well. Modifying dental light is also another way to modify the environment and make it more sensory friendly.

It is also important that autistic individuals are assigned to the same dentist, and they should get to know the dentist very well to be more familiar and comfortable.

- **Modification of dental tools and instruments:** Many dentists struggle with putting the instruments anywhere near the autistic person mouth. this stems from many reasons, for example the autistic individual believe that this tool will cause them pain. The best way to deal with this is the show, tell, do technique which was discussed previously. Another reason as to why an autistic individual refuses dental instruments is the instruments being unfamiliar for them.

  Another way to overcome this is to design dental instruments to look like items they put in their mouths. For example, a dental mirror can be re-designed to look like a spoon, a local anesthesia syringe could be designed to look like a lollipop or other food items, and an ultrasonic scaler can be designed to look like a toothbrush.

It is also critical that the patient's comfort and safety is taken into account, so one thing that can be done is providing bite blocks and tools that help keep the mouth open. These tools can be attached to highspeed handpieces and ultrasonic scalers, and then removed for sterilization. Another suggestion is that the buttons on the dental chair be kept hidden under the chair in a place only the dentist can access easily. Another modification that can be made to dental chairs is adding a voice prompt that informs the patient that the chair will now be raised, or the chair will go down and so on.

Due to the sensory issues that individuals with ASD experience, some of them might be sensitive to lights, so one thing that can be done is removing the dental light above the patient and replacing it with a smaller light that can be attached and detached from the instruments or modifying each instrument to have its own light source.

- **Providing at least one expert in the field of SCD per clinic:** This solution is difficult to implement due to the current lack of experts in the field. But what can be done is to gather available human resources and collect data about dentists who have the knowledge, skills, and confidence to deal with mild and moderate autistic patients with the ability to cooperate, then relocate them and assign them to different clinics.

Assigning paedodontists with experience with inhalation or conscious sedation in multiple clinics in various areas is also recommended.

It is also suggested that more investment is to be made to support these dentists and assist them in getting proper education to expand their expertise regarding SCD.

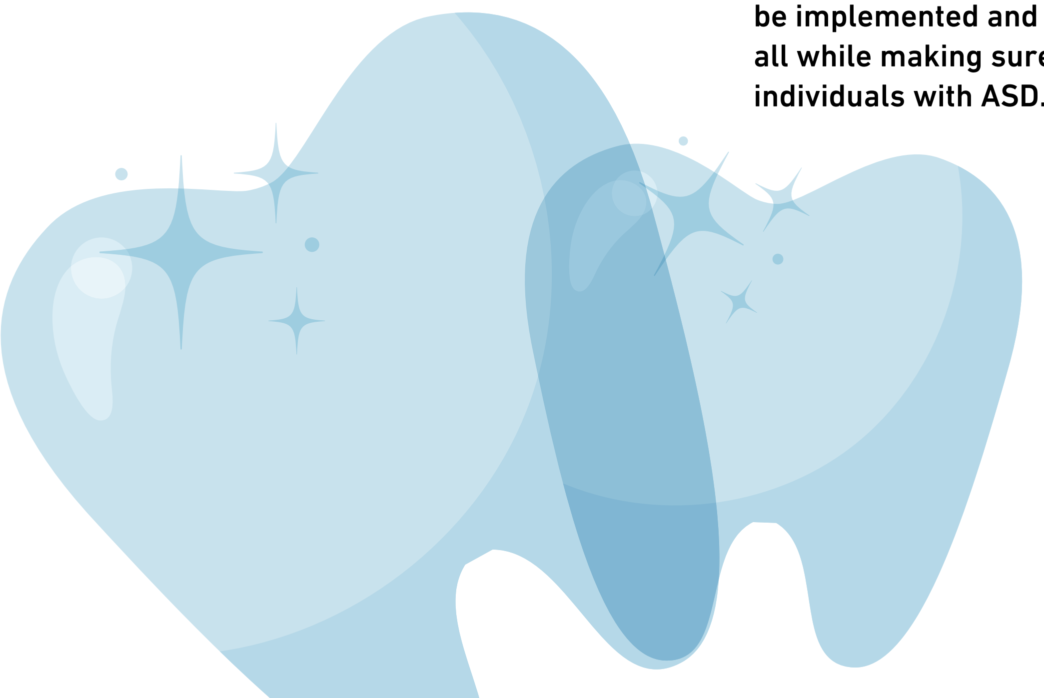
- **Better awareness for parents and caretakers:** Dental facilities and dentists should do better regarding educating parents and caretakers of the importance of oral health for autistic individuals. They should always emphasize the importance of brushing, flossing, and regular dental visits. They should also make sure that parents and caretakers are aware of the oral health problems that come with autism.

  On the other hand, caretakers and parents must not neglect the importance of oral health for their autistic children and individuals. They must be well aware of the oral health implications of autism, and they should always ask for more information from their dentists whenever required.

  Moving on to the last section, which is the main and most important aspect of this proposal, I will discuss in detail the main idea on how dentists can contribute to their duty and help people with autism gain more access to dental care.

- **Designing an application for people with autism:** The idea is to create an application for people with autism to gain more access to dental services. More details below will be highlighted.

Aspect	Detail
What is it?	An application for mobile devices that enables autistic individuals to find suitable dentists, book appointments, and review their past appointments.
Who is it designed for?	Individuals with Autism Spectrum Disorder (ASD), their caretakers or parents, dentists, medical doctors, and pharmacists.
How will it help individuals with ASD?	• Provides access to dentists' profiles for informed selection. • Enables appointment booking, reducing stress. • Includes personal profiles showing treatment plans, previous treatments, radiographs, and clinical notes. • Sends reminders for appointments. • Allows simple consultations by submitting questions to dentists.
How will it help dentists?	• Supports patient selection by ensuring dentists are familiar with Special Care Dentistry (SCD) are chosen. • Serves as a database for storing patient information, templates, and medical history. • Allows access to past treatments without editing capability. • Enables prescribing medications directly via the app. • Facilitates referrals to specialized colleagues, saving time and reducing patient stress.
Why are medical doctors and pharmacists included?	• Pharmacists: Verify and dispense medications prescribed via the app. • Medical Doctors: Record patient allergies, medications, and health history. Assist with blood work requests and upload results for dentist review.
What are some other features?	• Virtual reality: Allows autistic individuals to simulate dental visits and interact with tools. • Incorporates tawasol symbols for better communication (e.g., dentist, open mouth, rinse mouth).
How can we improve it in the future?	• Expand to include individuals with other disabilities (e.g., Down syndrome, cerebral palsy, visual impairments). • Develop a similar application for the general population. • Add a voice recognition feature for visually impaired users.



4. Conclusion

This is the end of this proposal that explains how autism and oral health are related and offers many solutions to improve issues ASD individuals face in regard to receiving dental care.

To put everything into perspective, individuals with ASD are often affected by oral complications that can be due to sensory regulation issues, challenging behaviors, intellectual disability, or even due to co-morbid conditions that have a high co-occurrence rate with ASD such as ARFID and EDS.

According to many referenced studies, if dentists do not get enough education and exposure in regards of how to care for disabled individuals, meaning that many dental schools or colleges lack in the curricula of special care dentistry.

In the end, it is important that dentists and authorities come together with their thoughts, ideas, and suggestions on how to be more inclusive of autistic individuals as they are a part of our society and deserve oral care like their neurotypical peers. These ideas must be implemented and carried out accordingly all while making sure that they are useful for individuals with ASD.

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Early Detection of Autism Spectrum Disorder (ASD) in Children using Machine Learning

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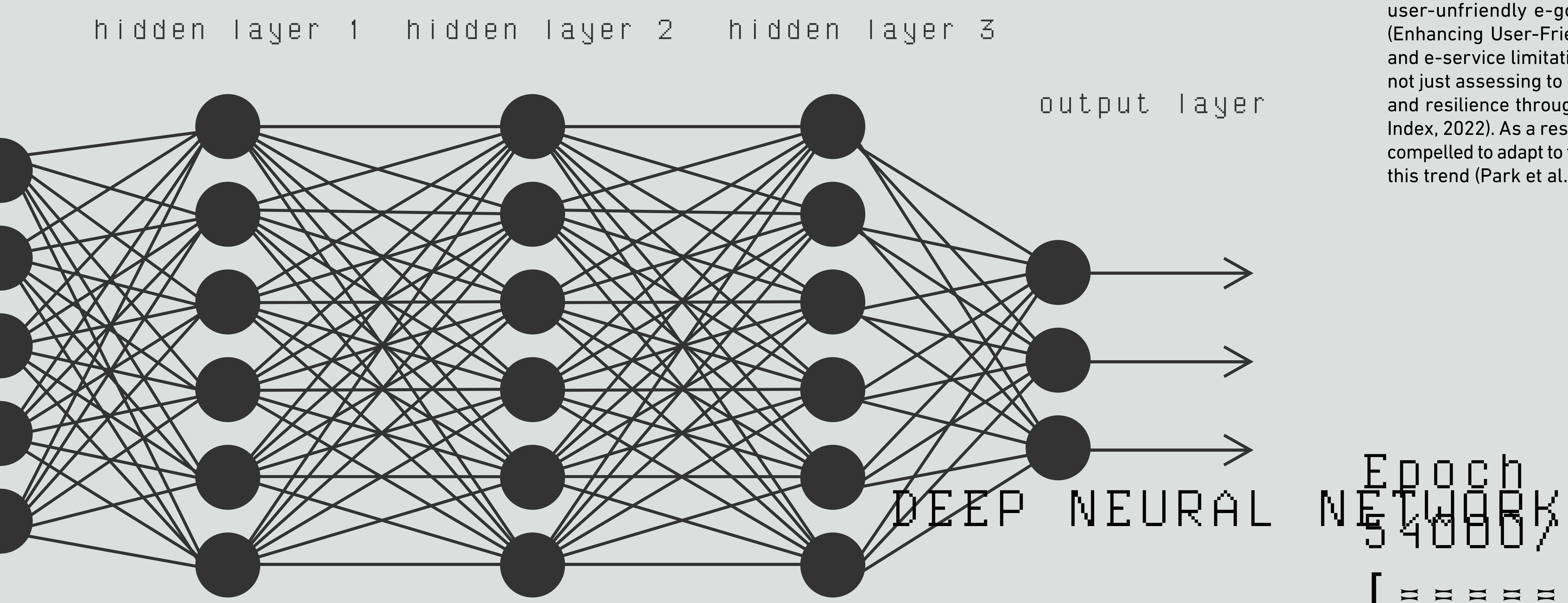

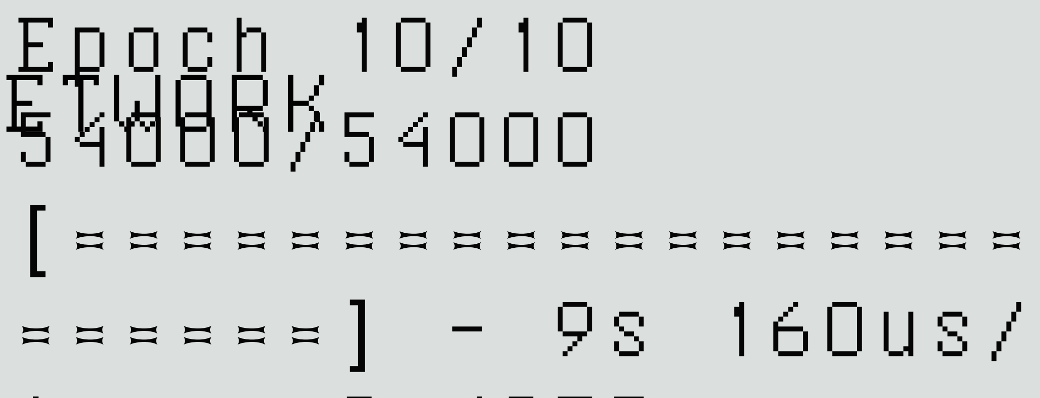

Keywords - Autism Spectrum Disorder; Machine Learning; Artificial Intelligence; Decision Tree; Random Forest; Logistic Regression.

Abstract- Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition that affects communication, social interaction, and behavior, necessitating early diagnosis for effective intervention. This study aims to improve the accuracy and efficiency of ASD screening for toddlers through the application of machine learning models utilizing the Q-CHAT-10 dataset. Following the CRISP-DM methodology, we conducted comprehensive data preparation, feature selection, and model evaluation. We compared the performance of three machine learning models: Logistic Regression, Decision Tree, and Artificial Neural Network (ANN). The ANN exhibited the highest performance, achieving an accuracy of 98.5% and an F1-Score of 98.5%, followed closely by the Decision Tree model with an accuracy of 98.23%. Logistic Regression, although less precise, maintained a reliable performance with an F1-Score of 91.02%. This research highlights the potential of AI-driven pre-diagnostic tools to expedite ASD screening processes, significantly reducing waiting times for assessments. Future work will focus on integrating clinical datasets and exploring multi-modal data, including eye-tracking and behavioral video analysis, to further enhance diagnostic accuracy and support early intervention strategies in real-world settings.Performance Index (PAPI), indicating user-unfriendly e-government service interfaces' challenges (Enhancing User-Friendliness, 2023). Addressing digital divide and e-service limitations is crucial, along with monitoring usage not just assessing to enhance transparency, citizen engagement, and resilience through DT by public agencies (GovTech Maturity Index, 2022). As a result of the COVID-19 outbreak, societies were compelled to adapt to the digital era through policies that supported this trend (Park et al., 2022).

1. Introduction - Autism Spectrum Disorder (ASD) is a neurodevelopmental condition that influences how individuals perceive their environment and interact socially. It is marked by difficulties in communication, social interactions, and repetitive patterns of behavior [1]. Although prevalence rates vary across studies and regions, approximately 1 in 100 individuals globally are believed to be affected by ASD [2]. While the exact causes remain unclear, research points to a combination of genetic and environmental factors playing a role in its onset [3].

Between 1998 and 2018, ASD diagnoses in the UK rose dramatically, particularly among adults and females. However, there has been little progress in increasing early diagnoses during childhood, despite efforts to identify cases before the age of three [4]. Early identification of ASD is critical, as studies show that interventions are most effective when introduced before a child turns eight [5]. Intensive behavioral therapy in early childhood has been proven to significantly enhance cognitive abilities, language development, and social skills in preschool-aged children with [6]. In the UK, the waiting time for an initial assessment of ASD can be as long as 14 months [1]. As of December 2022, approximately 140,000 individuals were waiting for appointments. Obtaining a diagnosis is essential for children to receive the necessary support and resources. For example, an ASD diagnosis can help families better understand their child's specific needs and ensure access to tailored educational support, such as Individual Education Plans (IEPs) and additional assistance in schools [7]. Given the complex and diverse nature of ASD, diagnosis often requires a collaborative approach involving multiple disciplines. For children, the process may include interviews with parents, observations of behavior, cognitive tests, and medical evaluations [8]. However, the unclear origins of ASD and the lengthy diagnostic procedures make accurate and timely diagnosis challenging. Current methods often involve prolonged observation and comprehensive evaluations across various domains [9]. Common diagnostic tools include the Autism Diagnostic Interview-Revised (ADI-R) and the Autism Diagnostic Observation Schedule (ADOS) [10]. The ADI-R relies on semi-structured interviews with caregivers or parents [11], while the ADOS assesses behaviors through age-specific, semi-structured play activities [12]. To help reduce the waiting times for clinical ASD assessments and facilitate earlier diagnoses for children, pre-diagnostic screening tools are frequently utilized to support referral processes. These tools usually involve standardized questionnaires that can be completed by parents or caregivers for children, or self-administered by adults [13]. Enhancing the diagnostic process is essential for ensuring individuals with ASD receive early intervention and the necessary support. Streamlined assessments could significantly improve developmental outcomes for those on the autism spectrum.

NEURAL NETWORK

2. Materials and Methods - The CRISP-DM (Cross-Industry Standard Process for Data Mining) methodology is employed in this paper to evaluate the accuracy of early detection of ASD using different machine learning techniques.

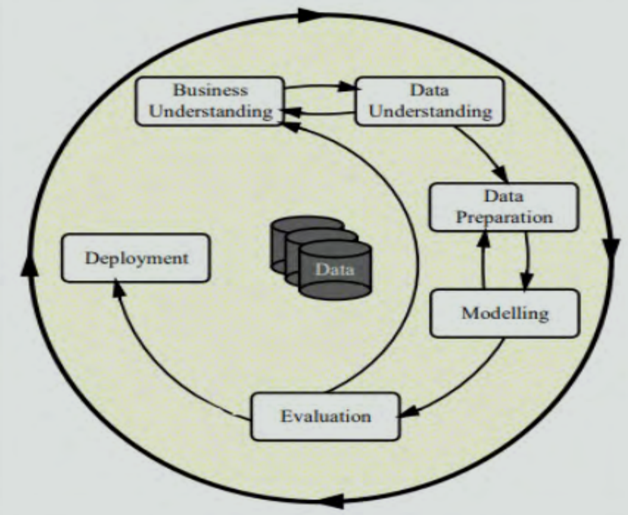

Figure 1. Phases of CRISP-DM [14]

2.1. Data Understanding - The data has been taken from Kaggle it is called as 'Autistic Spectrum Disorder Screening Data for Toddlers'. They introduce a novel dataset focused on autism screening for toddlers, which includes key features that can be leveraged for advanced analysis, particularly in identifying autistic traits and enhancing the classification of ASD cases. This dataset captures ten behavioral indicators (Q-Chat-10) along with additional individual characteristics that have been demonstrated to effectively differentiate ASD cases from controls in behavioral science studies. The dataset is predictive and descriptive in nature, containing nominal/categorical, binary, and continuous data types, making it suitable for classification tasks, as well as clustering, association analysis, or feature assessment. It falls under the domain of medical, health, and social sciences and consists of 1,054 instances with 18 attributes, including the class variable, and contains no missing values. The attributes include ten behavioral items from the Q-Chat-10 questionnaire (A1-A10), where responses were mapped to binary values ("1" or "0"). For questions A1 to A9, responses of "Sometimes," "Rarely," or "Never" were assigned a value of "1," while for question A10, responses of "Always," "Usually," or "Sometimes" were assigned "1." If the total score across all ten questions exceeded 3, the individual was flagged as potentially exhibiting ASD traits; otherwise, no ASD traits were identified. Additional features in the dataset were collected through the "submit" screen of the ASDTests screening app, with the class variable automatically assigned based on the user's score during the screening process. [15].

2.2. Explanatory Data Analysis - Exploratory Data Analysis (EDA) was performed on the dataset to explore the key attributes and patterns associated with Autism Spectrum Disorder (ASD) in toddlers. The findings suggest that approximately 69.1% of toddlers worldwide are affected by ASD. The highest number of ASD cases are observed among White Europeans, followed by Asians, while Native Indian and Pacifica ethnic groups show a higher susceptibility to ASD. Males are more likely to be diagnosed with ASD compared to females. Additionally, toddlers who have had jaundice are more likely to be diagnosed with ASD than those without jaundice. Interestingly, the majority of children with ASD do not have family members with the condition, indicating that ASD may not be predominantly hereditary. The tests for most ASD cases are completed by family members, and toddlers around the age of 36 months exhibit the highest number of ASD diagnoses. The likelihood of ASD is greatest at 2 years of age, and toddlers with a Q-Chat-10 score above 3 are more likely to be diagnosed with ASD. Furthermore, most toddlers with autism do not react emotionally when their loved ones are upset, highlighting a common lack of emotional response among these children. To visualize these findings, several graphs and charts were created to better illustrate these trends and insights.

2.3. Data Preparation - In the Toddler dataset, there were no missing values for the selected features, allowing all 1,054 samples to be used in training. However, both the Child-Adolescent and Adult datasets contained missing values, which were represented by '?' or values falling outside of the expected range. In the Child-Adolescent dataset, 4 records were excluded due to missing age values, while an additional 46 records were removed because the 'Relation,' 'Ethnicity,' and 'Country_of_Res' fields were all marked with '?'—indicating either incomplete data or potential errors in form completion. Although these fields were not included in the model, the significant gaps in data suggested these records might be invalid. In the Adult dataset, 2 records were removed due to missing age values, and 1 record with an age of '383' was excluded as an outlier. Furthermore, 93 records were removed because of incomplete 'Relation,' 'Ethnicity,' and 'Country_of_Res' fields, which raised concerns about the validity of the data. The Child-Adolescent dataset consisted of 346 records, while the Adult dataset had 608 records. To standardize the data, the age attribute was normalized using a MinMaxScaler, scaling the value between 0 and 1. Since all other features were binary, this normalization prevented the age value from distorting the model. The models were evaluated both with and without this normalization step to assess its impact on performance.

2.4. Feature Selection - The initial dataset included 18 variables, with 15 selected for model training. The variable "Who completed the test" was excluded as it was irrelevant to the outcome. Following [15] recommendation, the "QCHAT-10 score" was also removed since it was used to assign the class label, which could lead to overfitting. Additionally, the "Ethnicity" variable was omitted due to its imbalance in the dataset, which could introduce unintended biases. The remaining features selected for training included all 10 Q-CHAT items, along with "Age," "Sex," "Jaundice," and "Family member with ASD." The target variable was the "Class" variable. To prepare the data for training, the "Sex," "Jaundice," "Family member with ASD," and "Class" variables were encoded into binary integers using the Label Encoder function. For the Child, Adolescent, and Adult datasets, which were similarly structured with 20 features, 13 were selected for training. As in the Toddler dataset, the features "Ethnicity," "Country of Residence," and "Relation" were removed. The "Age description" feature was excluded since it was identical across datasets (e.g., "4-11 years" in the Child dataset). The "result" and "autism" features were also discarded, as they were used to generate the "Class" variable. The "Sex," "Jaundice," and "Class" variables were converted to binary integers using the Label Encoder for consistency in model training.

2.5. Modelling - For predicting accuracy on ASD dataset, three models were applied: Logistic Regression, Decision Tree (DT) and Artificial neural network (ANN). The system was implemented on Google Colab, 5 a cloud-based Jupyter notebook environment offering access to computational resources, including GPUsColab also facilitates easy collaboration, making it useful for research projects.

2.6. Evaluation - Evaluating the model is a critical phase in AI-based learning, focusing on assessing how well the trained models perform. This step ensures that the model generalizes effectively to new data and guides decisions on deployment and further improvements. The following metrics and techniques contribute to a comprehensive evaluation:

Accuracy measures the overall performance of the model by showing how often it correctly classifies or predicts outcomes.

Accuracy = TP + TN / TP + TN + FP + FN

Precision measures the accuracy of positive predictions, with higher precision indicating more correct positive classifications.

Precision = TP/ TP + FP

Recall assesses the model 's ability to detect true positive cases. A higher recall means the model effectively identifies actual positive instances.

Recall = TP/ TP + FN

The F1-score combines precision and recall into a single metric by calculating their harmonic mean, offering a balanced evaluation of both.

F1- Score = (2 × precision × recall) / (precision + recall)

3. Results and Discussion

3.1 Logistic Regression - his implementation evaluates a Logistic Regression model using pre-scaled training and testing data. The Logistic Regression model is configured with max_iter=1000 to ensure convergence during optimization, and a random_state=42 for reproducibility. The model is trained on the scaled training data, and predictions are made on the test set. The performance of the model is assessed using key metrics, including accuracy, precision, recall, and F1-score. These metrics are structured into a DataFrame for comparison with other models. Additionally, the model's learning behavior is analyzed using a learning curve. The learning_curve function from scikit-learn computes training and validation accuracies for different training set sizes using cross-validation. The model achieved an accuracy of 90.4%, with a precision of 91.49%, a recall score of 90.56%, and an F1-score of 91.02%.

3.2 Artificial Neural Networks - The Artificial Neural Network (ANN) model implemented in this code is designed for binary classification, with a structure consisting of an input layer, one hidden layer, and an output layer. The input layer has 64 neurons, and the hidden layer uses the ReLU activation function to introduce non-linearity. The output layer uses a Sigmoid activation function to predict probabilities for binary outcomes. The model is compiled using the Adam optimizer and the binary cross entropy loss function, with accuracy as the evaluation metric. To prevent overfitting, the EarlyStopping callback is utilized, monitoring the validation loss and stopping training early if the model's performance plateaus over 10 epochs. The training process uses a batch size of 20, a maximum of 100 epochs, and a validation split of 20% to assess the model's generalization on unseen data. The model achieved an accuracy of 98.5%, with a precision of 98.72%, a recall score of 98.46%, and an F1-score of 98.5%.

3.3 Decision Tree - This implementation evaluates a Decision Tree Classifier using pre-scaled training and testing data. The Decision Tree model is optimized with specific hyperparameters such as criterion='entropy', min_samples_split=10, and min_samples_leaf=5 to improve generalization and mitigate overfitting. After training, predictions are made on the test data, and the model's performance is assessed using metrics like accuracy, precision, recall, and F1-score. These metrics are structured into a DataFrame for comparison with other models. Additionally, a learning curve analysis is performed to visualize the model's learning behavior. Using the learning_curve function from scikit-learn, training and validation accuracies are computed for varying training set sizes. The mean and standard deviations across cross-validation folds are plotted to analyze how the model generalizes as more data is introduced. The model achieved an accuracy of 98.23%, with a precision of 97%, a recall score of 99 %, and an F1-score of 98%.

3.4 Comparative Results

Model	Accuracy	Precision	Recall	F1-Score
Decision Tree	98.23%	97%	99%	98%
ANN	98.5%	98.72%	98.46%	98.5%
Logistic Regression	90.4%	91.49%	90.56%	91.02%

Table 1. Models Results

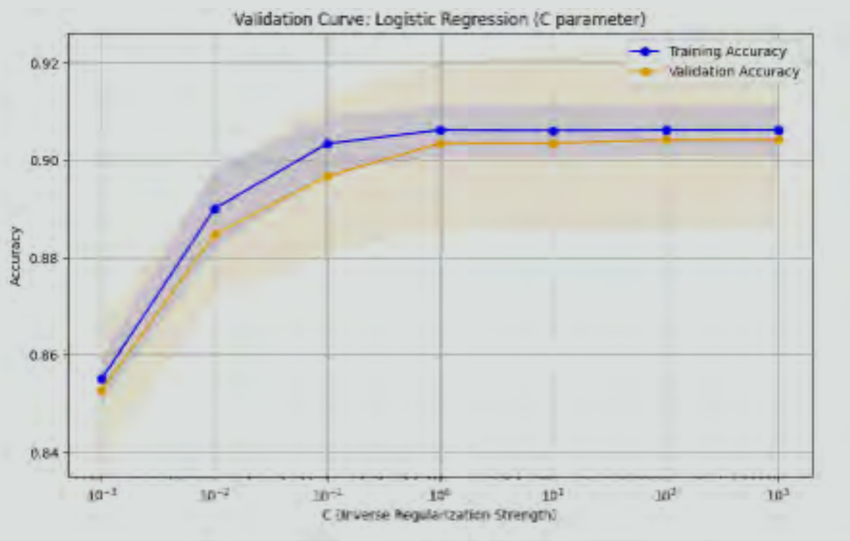

Figure 2. Logistic Regression Validation Curve

The graph represents a validation curve for Logistic Regression, illustrating the effect of the C parameter (inverse regularization strength) on model accuracy for both training and validation datasets. On the x-axis, smaller values of C indicate stronger regularization, which simplifies the model, while larger values reduce regularization, allowing the model to capture more complex patterns. At low C values, both training and validation accuracy are low due to under fitting, as excessive regularization prevents the model from learning effectively. As C increases to a moderate range, the model achieves a balance, with both training and validation accuracy improving and converging, indicating proper generalization. However, at very high C values, training accuracy continues to rise, but validation accuracy plateaus or slightly decreases, suggesting overfitting, where the model captures noise in the training data and fails to generalize. The shaded areas represent variability across cross-validation folds. The graph shows that the optimal C value lies in the mid-range, where the model achieves high and balanced accuracy on both datasets.

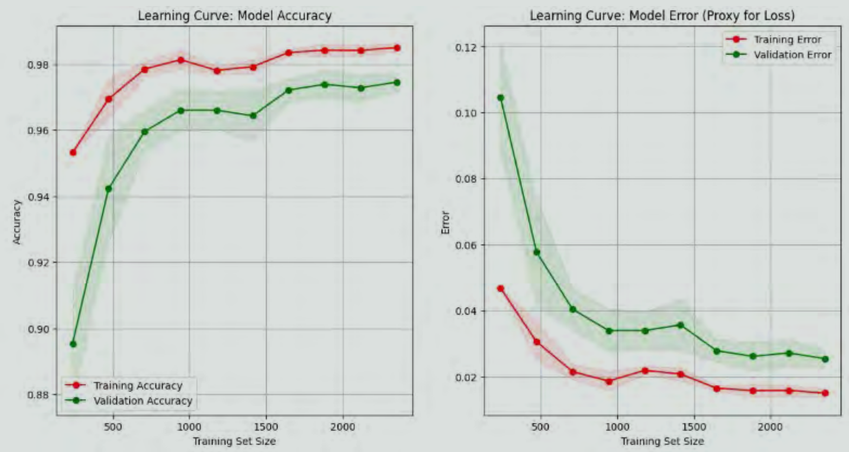

Figure 3. Decision Tree Learning Curve

The learning curves illustrate how the model's accuracy and error evolve as the training dataset size increases. In the accuracy graph, the training accuracy starts very high when the dataset is small because the model memorizes the data. However, validation accuracy is much lower at this stage due to poor generalization. As more data is added, training accuracy slightly decreases while validation accuracy steadily improves, with both curves converging and stabilizing as the training set grows, indicating a well-generalized model. In the error graph, the opposite trend is observed: training error is initially very low for small datasets but increases as the model transitions from memorizing to generalizing. Validation error starts high but decreases significantly as the dataset grows, eventually converging with training error at a low level. This demonstrates that the model performs well on both seen and unseen data, achieving a good balance between bias and variance.

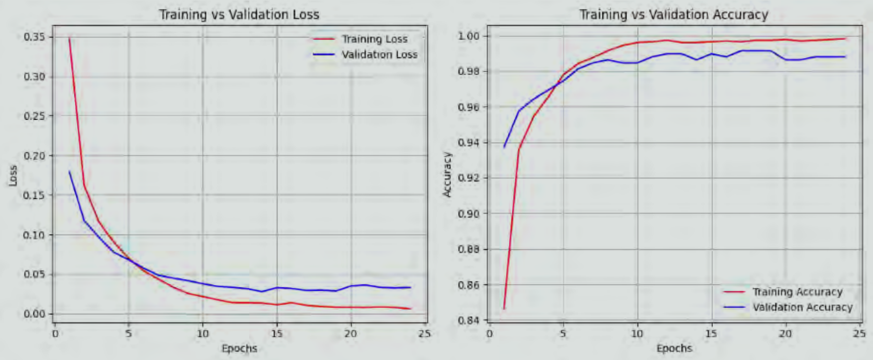

Figure 4. ANN Validation Curve

The graphs illustrate the learning behavior of an Artificial Neural Network (ANN) model over 25 epochs. The left plot shows the training and validation loss, where both curves steadily decrease during the early epochs as the model learns. The training loss (red) drops quickly, and the validation loss (blue) follows a similar trend, eventually stabilizing at a low value. This indicates that the model is not overfitting or under fitting, achieving good generalization. The right plot depicts training and validation accuracy. The training accuracy (red) rises rapidly, approaching 100%, while the validation accuracy (blue) also increases and stabilizes slightly lower than the training accuracy. The small gap between the two curves suggests the model generalizes well to unseen data without overfitting.

4. Conclusion and Future Scope - The primary goal of this project was to leverage AI to create an accessible and transparent approach to ASD screening, aiming to help reduce the waiting times for a diagnosis. The applied machine learning methods showed a good performance to early detect the ADS. The Artificial Neural Network (ANN) achieved the highest overall performance, with an F1-Score of 98.5%, while the Decision Tree model also showed excellent results. The Logistic Regression model, though less effective than the other two, still performed reliably with an F1-Score of 91.02%. The next steps should focus on training the models with a multi-modal dataset, integrating clinical classifications, and collaborating with healthcare professionals for further refinement. To improve accuracy, future research should focus on developing a dataset based on individuals who have undergone clinical assessments and been diagnosed accordingly. Additionally, combining different types of data, such as videos and eye-tracking information, could further enhance the model's precision. A potential improvement would be to develop models that incorporate multi-modal data, which could enhance objectivity and minimize the biases that are often seen in ASD screening and diagnosis.

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Arabic Algerian Sign Language Translation System Based on 3D Avatar Technology

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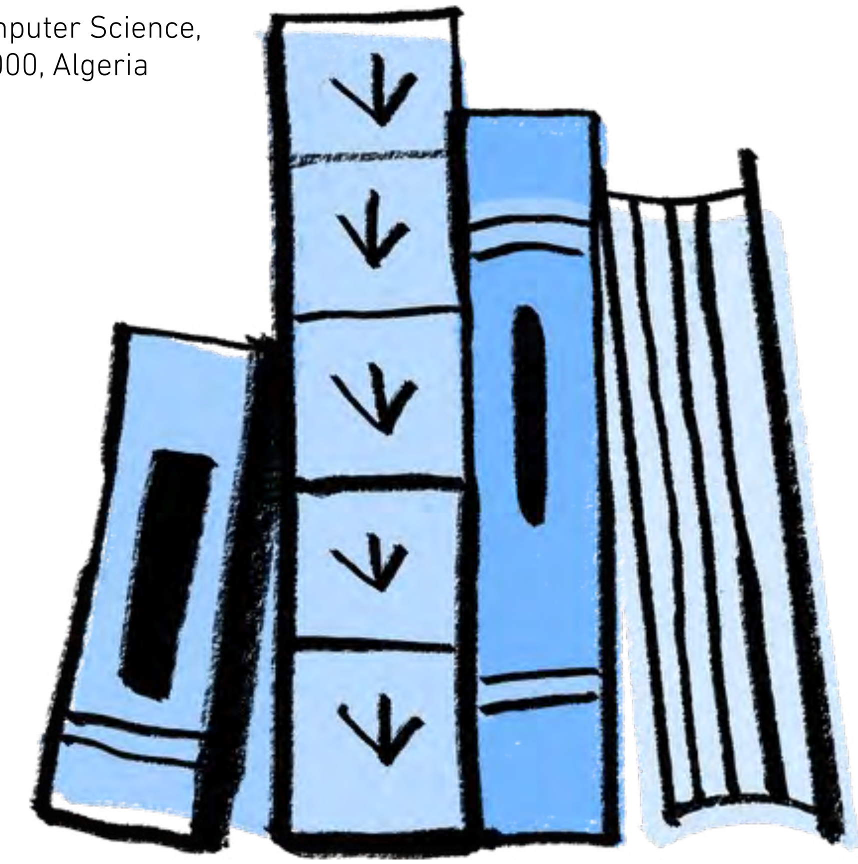

Abstract: This work focuses on the creation of tools to help deaf people learn Arabic Algerian Sign Language (ALSL), specifically an automatic translation system with a 3D avatar for accurate and dynamic sign representation. The system encodes ALSL signs using the Notation System Method (NSM), which is principally based on the Hamburg Notation System (HamNoSys).

A shallow analysis of the linguistic complexity of ALSL is offered, as well as the obstacles inherent in developing technological solutions to facilitate proper translation. To ensure correctness, the development approach involved working with ALSL translation experts at each level. The system's lexicon, consisting of 417 words, achieved a certified accuracy rate of 75.53%. These results represent a substantial step forward in 3D avatar-based sign language simulation, with opportunities for further refinement and development.

Keywords: Arabic Algerian Sign Language, 3D Avatar, HamNoSys, Deaf Community, Translation System.

1. Introduction

The rise of digital technology has created unprecedented opportunities for removing communication obstacles, promoting inclusivity, and accessibility. Closing the communication gap between the deaf and hearing communities is a critical area where technology has the potential to influence substantial change. Sign languages, which are visual languages defined by hand gestures, body movements, and facial emotions, are integral to the daily existence of millions of deaf individuals globally. Nonetheless, disparities among sign languages, coupled with a deficiency in universal comprehension, can obstruct efficient communication between sign language users and individuals unacquainted with these languages. This study details the creation of an automated translation system adapted for Arabic Algerian Sign Language (ALSL) utilizing 3D avatar technology. The project seeks to address communication deficiencies for ALSL users by providing a 3D avatar-based solution that dynamically and precisely depicts ALSL signs, utilizing sophisticated systems engineering and web technologies. This dynamic translation technology offers a compelling user experience and guarantees the accurate visual depiction of ALSL, improving accessibility for both deaf and hearing users. The document is organized to assist readers in understanding the creation of a 3D avatar-based translation system for Arabic Algerian Sign Language (ALSL). The document commences with an overview of sign languages, emphasizing the historical context and structural aspects of Algerian Sign Language, thereafter presenting a literature analysis on progress in sign language translation and 3D avatar technology. The system design portion outlines the architecture, objectives, and critical design choices for developing an accessible platform, whereas the implementation section elaborates on the technical procedures, encompassing hardware, software, and motion capture for gesture animation. Each part develops upon the previous one, offering a unified strategy for improving communication within Algeria's deaf community.

2. Background

Sign language has been officially recognized as the principal language of the deaf in Algeria, as mandated by a law passed on May 8, 2002. The Algerian Sign Language (ALSL) derived from the French Sign Language (Langue des Signes Française, LSF). ALSL's history and evolution highlight its regional variances and lack of uniformity. The language's non-uniformity distinguishes it from others and warrants further study to understand regional variances and their impact on the overall language.

Some ALSL variations include: Algerian Sign Language of Laghouat, which is used by many deaf individuals in the province and adjacent areas, including cities and villages [13]; Algerian Sign Language of Oran is widely used by the Deaf community in northern Algeria, especially in Oran [11]; Adrar, located in southern Algeria, has a Deaf community that uses Algerian Sign Language [15]. In 2017, the National Foundation for Media Contact in Algeria produced the first Algerian Sign Language Dictionary [17]. The dictionary includes images of sign language vocabulary accompanied by captions in Arabic and French. It lacks grammar rules and structured phrases, but instead uses Arabic grammar and structure to express meaning in sign language[17].

3D virtual avatars are increasingly used to meet the educational needs of deaf and hearing-impaired students who often struggle with spoken language literacy [5]. Sign languages are essential for their communication, enabling interaction within their communities and with hearing individuals [23]. To support social integration, sign language interpretation systems have been developed to convert text and speech into signed language through 3D avatars, facilitating education, accessibility, and research [25]. These systems also aid in documenting and preserving sign languages for future generations [23, 25].

A 3D avatar is a three-dimensional recreation of a real or imagined The character in the digital world. An artist can create this type of computer-generated character from the base up or replicate it as a scanned model of an individual. A 3D human avatar typically consists of a geometric mesh in a neutral pose with textures and a skinning mechanism for movement simulation. Essential elements like materials, textures, and accessories (clothing, hair) add realism.

Recent developments in 3D technology have enabled the creation of detailed 3D avatars that have applications across various fields, such as gaming, virtual environments, fashion, healthcare, and the military. These avatars enable customization for individual needs, from sizing to specific functionalities and advancing applications like disease diagnosis [2, 6].

The 3D avatar ecosystem uses file formats like FBX (Autodesk), OBJ (Wavefront), and glTF (Khronos Group) to exchange geometry and animation data. Advances in laser scanning, white light scanning, photogrammetry, and machine vision have enabled high- accuracy 3D data capture, supporting fields from biomedical engineering to film production [9].

3. Related works

Researchers have made significant advances in designing systems to animate and translate sign languages, utilizing a variety of technologies and approaches. Bouzid et al. developed a web-based ASL system that uses SignWriting Markup Language and low-poly 3D avatars for visual representation [3]. Othman et al. contributed significantly to ASL transcription by creating a new XML-based machine translation model [21].

Kaur et al. used SiGML technology and the JA Signing App to translate Indian Sign Language words [12]. Punchimudiyanse et al. created a Python and Blender application to animate words in Sinhala Sign Language (SSL) without the need for video or motion capture[22]. Gonçalves et al. used C++ and the Irrlicht animation engine to produce 3D avatar animations for Brazilian Sign Language [10]. Da et al. used the Hamburg Notation System to translate Viennese sign language into 3D animations for television news [4].

Al-Barahamtoshya et al. created a system for translating Arabic text to Arabic Sign Language (ArSL) that included a speech module and transformational rules [1]. Luqman et al. developed an Arabic Sign Language Gloss System to efficiently express Arabic signs and words [14].

Brour et al. used video sequences and a rule-based system to accurately depict Arabic Sign Language [16].

The Mada Assistive Technology Center created the BuHamad Project, Qatar's first virtual 3D sign language avatar for Qatari Sign Language (QSL). This project integrates AI and motion capture to deliver real-time translation from Arabic text into QSL. It supports online machine translation and enables expanded accessibility for the deaf community in Qatar by allowing digital interactions across sectors [20]. In related work, [19] investigate the acceptance of signing avatars, specifically the culturally modified BuHamad avatar, among Deaf and Hard of Hearing individuals in Qatar. Results indicate that participants predominantly possess favorable sentiments regarding the signing avatar and its capacity to improve accessibility.

4. Proposed methodology

Our approach focuses on developing a comprehensive lexicon for Algerian Sign Language (ALSL), as illustrated in Figure 1. This dictionary is constructed from a pre-existing dataset of sign language videos annotated with HamNoSys notation. Utilizing the linguistic similarities between ALSL and French Sign Language (LSF), we right away import HamNoSys notations from the dataset for words common to both languages. ALSL experts assist the manual adding of new entries and the editing of Arabic terms absent from the DictaSign dataset, so ensuring accuracy and comprehensiveness.

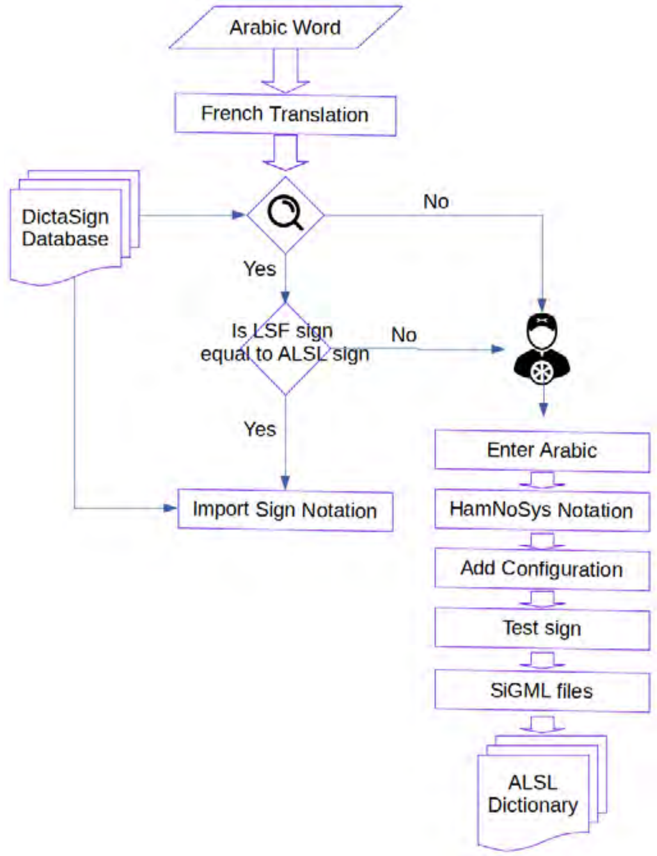

Figure 1. The ALSL dictionary construction process

The subsequent stage entails transforming the assembled HamNoSys notations into SiGML, a markup language suitable for 3D avatar rendering. ALSL specialists assess the resultant lexicon to confirm its accuracy. Furthermore, we established a system for converting Arabic text into 3D ALSL animations, with the system architecture shown in Figure 2. This system firstly preprocesses the text, conducts a glossary lookup in the ALSL lexicon, and finally translates the appropriate SiGML notation into a 3D avatar movement. This integrated methodology of dictionary building and system development seeks to establish a dynamic and accessible translation platform for Arabic-speaking ALSL users.

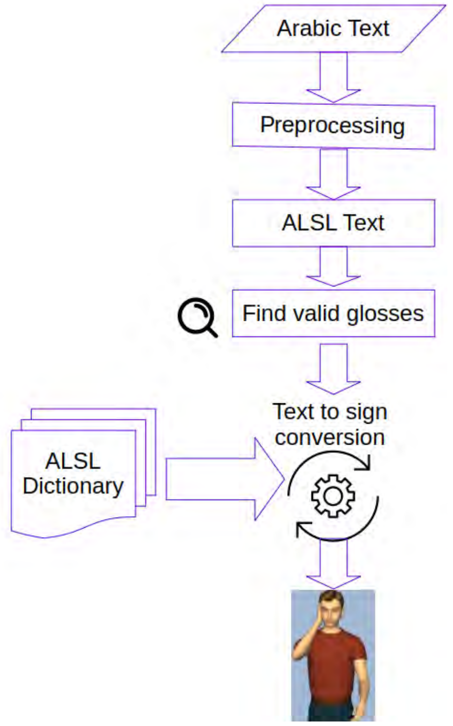

Figure 2. System architecture

5. Implementation

The following section provides a comprehensive overview of our development process of Automated Arabic Algerian Sign Language (ALSL) Translation System, highlighting the challenges faced and the solutions implemented.

Development Tools
The Notation System Method (NSM) involves the use of programming languages such as JavaScript, HTML, and CSS. Here we cite tools used to implement Notation System Method (NSM): for ALSL words translation into 3D avatar are:

- **HamNoSys:** The Hamburg Notation System (HamNoSys) is used for encoding sign language gestures [18].
- **SigML:** The Sign Gesture Markup Language (SigML) converts HamNoSys notations into animations displayed by the 3D avatar. This bridge between textual descriptions and visual representation ensures accurate and consistent gesture animations [8].
- **eSIGN Editor:** This tool is used to create and manage sign language dictionaries, vital for ensuring the accuracy and comprehensiveness of the ASL gestures performed by the avatar [27].
- **CWASA SIGML Player:** SIGML Player is a tool used to animate sign language data encoded in SiGML (Signing Gesture Markup Language). This player forms part of the broader CWASA (CWA Signing Avatars) system, which synthesizes natural sign language performance using virtual human avatars.
- **CWASA Virtual Signing System:** The CWASA system enhances the visual signing capabilities of the avatar, allowing it to perform complex ASL gestures fluidly and naturally. This system ensures that the gestures are lifelike and expressive, adhering to the nuances of sign language [26].

Solution steps
This subsection provides a comprehensive description of the implementation of our proposal utilizing the Notation System Method (NSM). We outline each methodological step and supply specifics regarding the approaches used in each developmental phase, covering:

- **Data Collection:** Collecting and structuring the necessary data to develop a precise translation system.
- **ALSL Translation Dictionary building:** Developing a dictionary designed for Arabic Algerian Sign Language (ALSL) to enhance translation ability.
- **Translating HamNoSys to SiGML:** Converting HamNoSys notation into SiGML, a format suitable for 3D avatar rendering.
- **Text Processing:** Analyzing input text to ensure precise translation and presentation.
- **User Interface (UI) Derived from CWASA:** Creating an intuitive interface based on the CWASA architecture to improve accessibility and engagement.

Data Collection

- **Data Sources:** The approach primarily relied on the DictaSign dataset. This corpus includes 1,000 lexical items translated into four different sign languages, with our research focusing on the equivalents in French Sign Language. Collaborating with a team of experts, we translated over 300 words from the dataset, aligning sign performances between Algerian Sign Language and French Sign Language [7]. The dataset provides video clips of gestures for each word along with notations in HamNoSys notation, for example, in Figure 3, the word "give up" in French (LSF).

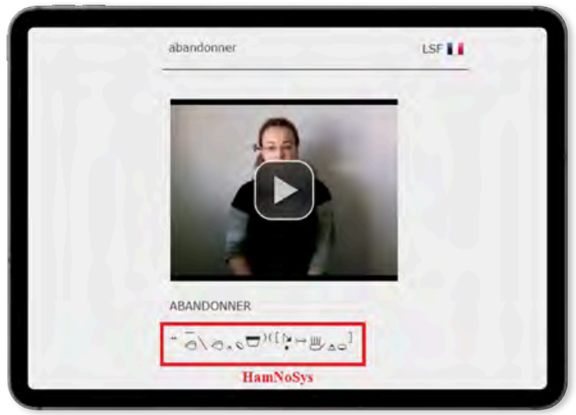

Figure 3. LSF representation in a video & in HamNoSys for the word "Abondonner"

We used videos of native performers of Algerian Sign Language for words that are not included in the DictaSign dataset. For example, we sourced videos from the "Algerian sign language Facebook page"[24], which regularly showcases Arabic words performed alongside their corresponding signs in Algerian Sign Language as showed in figure 4.

Figure 4: Algerian Sign Language gestures of "Eid al-Adha" عيد الأضحى

5.1. ALSL Translation Dictionary Creation

In this stage, the focus is on the first step of building the ALSL dictionary, which involves translating vocabulary entries (representing Arabic words) based on HamNoSys system using eSign editor.

The figure 5 shows a HamNoSys Translation for the word "أسرة" in ALSL using the manual translation method, and the figure 6 shows the imported HamNoSys Translation for the word "give up (Abandonner in french)" in LSF using the importing method.

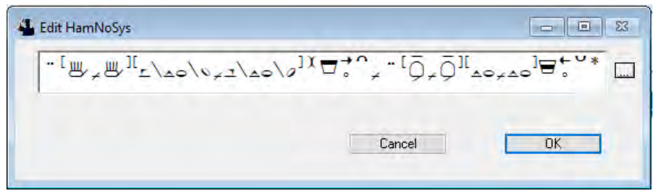

Figure 5: Manual HamNoSys Translation for the word "أسرة" in ALSL

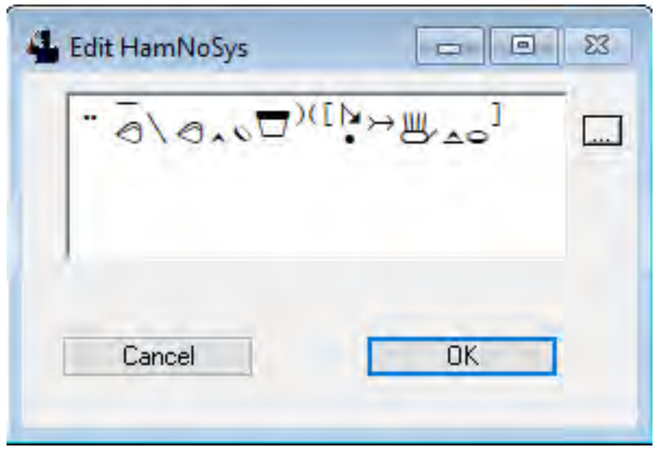

Figure 6: The imported HamNoSys Translation for the word "(Give up) Abandonner" in LSF

Testing and Validation After incorporating the Arabic word into the dictionary, we assessed the avatar's performance in sign language motion using HamNoSys encoding associated with the word. This evaluation was conducted through the 'Sign' function in the eSign editor, presenting results via the CWASA Sigml player application. Subsequently, we validated translation accuracy by comparing video recordings of native Algerian Sign Language signers or by soliciting feedback from experts in Algerian Sign Language.

5.2. Translating HamNoSys to SIGML

After completing the first step of building the dictionary, the translation data in this phase is saved in the form of SiGML files based on HamNoSys , which is readable by the 3D avatar. When describing the process of translating HamNoSys annotations into SiGML files and the avatar's interaction with these files. The HamNoSys notation is converted into SiGML, an XML-based format, by matching symbols to corresponding SiGML tags. This format is used to create 3D rendering software for sign language animation. The SiGML file is then used to animate gestures through a virtual avatar, controlled by the CWASA SiGML Player App.

The CWASA system uses JavaScript and WebGL technologies to translate SiGML into animations for real-time virtual avatars on web-based applications. Client applications send SiGML data via TCP/IP to the server, which processes it to control the avatar's movements. CWASA can also use XMLHttpRequest to dynamically fetch SiGML files or update avatar settings, enhancing user interaction and ensuring effective rendering of sign language animations.

5.3. Text Processing

To minimize issues for users, in this stage, we relied on developing specific algorithms to process Arabic textual inputs. The arabic text is preprocessed by using regular expression to clean text. And the use of Sliding Window Algorithm to address the issue of accurately recognizing phrases such as "بعد غد" ("the day after tomorrow") in Arabic text inputs, which are separated by spaces and thus might be incorrectly treated as separate entities, we employ the sliding window algorithm.

5.4. UI Based on CWASA

User Interface Design The user interface (UI) for the Automated Arabic-Algerian Sign Language Translation System is designed to be intuitive and user-friendly, allowing users to input Arabic text and view the corresponding Algerian Sign Language (ALSL) signs performed by a 3D avatar. A CWASA (Character and Word Alignment and Signing Avatar) is integrated into the UI to render the 3D avatar's sign language animations (cf. figure 7).

Figure 7: Arabic Algerian 3D Avatar Translator System UI Based on CWASA

6. Tests

The ALSL Translation System deployed on the website[1] so users could test it and see all its different pieces. Work was conducted in collaboration with specialists from the School for Deaf Children in Beni Slimane, who deal with Algerian Sign Language translations, and the association of Bouira province, which specializes in sign language translation.

Problems in synchronization were detected at the integration test level for interaction between the translation engine and 3D avatar animation. Still, these were resolved by optimizing the communication protocols among the various modules. It is confirmed that the flow from Arabic text input to 3D avatar animation is smooth with the correct sign displays.

User acceptance testing affirmed the interface's ease of use, with clear translations and a reasonable translation time. User comments led to changes to the control panel layout. All component-level tests passed, with initial issues rectified by improving input-handling code. Module optimization eliminated synchronization issues between the translation engine and the 3D avatar animation.

To ensure the accuracy and cultural relevance of the translation, we collaborated closely with experts in Algerian Sign Language (ALSL). This phase involved rigorous testing of the translation system using a comprehensive glossary of ALSL vocabulary. The experts' feedback was crucial for refining the system and improving its accuracy.

The following table (Table 1) displays the results of the system tests based on the feedback from experts in Algerian Sign Language translation.

The Overall Accuracy of our ALSL translation system = 75.53%.

Categories	Expert test	Correct	Percent	Incorrect translations
Pronouns	ok	3/3	100%	-
Nouns	ok	219/227	96.48%	أستاذ ألم، أم، إشارة، اقتصاد، امرأة، يونيو، مكتبة
Verbs	ok	76/78	97.44%	لا يعلم، يأخذ
Adjectives	ok	40/44	90.91%	آخر، صعب، مريض
Tools	ok	11/12	91.67%	كيف
Adverbs	ok	14/17	82.35%	أمام، تحت، صباح
Miscellaneous	ok	11/15	73.33%	فقط، مرة أخرى، مرحبا، من فضلك
Numbers	ok	19/21	90.48%	90 ,40
Total		315/417	75.53%	

Table 1. Dictionary evaluation

[1] https://3dasl-avatar.vercel.app

7. Conclusion

The Automated Arabic Algerian Sign Language Translation System is a big step forward in enhancing communication among Algeria's Deaf community. Using the Notation System Method (NSM), this study successfully developed a program that translates Arabic text into accurate and fluid ALSL motions performed by a 3D avatar.

The built dictionary, comprising 417 words, attained a verified accuracy rate of 75.53%. These results indicate a considerable step forward in 3D avatar-based sign language simulation, with prospects for further refinement and growth.

Several obstacles were addressed during the implementation, including the lack of high-quality ALSL datasets, the intricacy of motion capture technologies, and the complexities of effectively translating and animating sign language gestures.

In the future, we recommend focusing on expanding the ALSL dataset, enhancing the realism and precision of avatar animations, and optimizing system performance across various platforms. Collaboration with the ALSL community, along with further enhancement of the user interface, will be necessary to maintain the system's relevance and efficacy.

Acknowledgments
We sincerely thank Mr. Youcef Benyahia for his expert contributions to our 3D avatars and animations. Special thanks to Mrs. Dharbou Maroua, whose dedication as a sign language specialist greatly enhanced the quality of over 300 Algerian Sign Language (ASL) gestures. We are also grateful to the teachers of the school for the deaf in Beni Slimane, Medea, for their essential feedback during prototype testing.

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Autism and Play

An Overview of the Methodological Approach and Preliminary Results

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Abstract - Recent research has discussed co-designing with autistic children in several settings. However, none of these studies have investigated the inclusive play field. This project aims to co-design and evaluate a tool to promote inclusive, collaborative play with and for autistic children in an educational context. It is structured into three phases: Contextual Inquiry, Co-Design, and Joint Engagement Evaluation. This paper aims to provide an overview of the methodological approach used within this project and the preliminary results obtained. In the contextual inquiry phase, observations and interviews with specialists revealed key themes influencing collaborative play, such as the role of structured activities and inclusive environments in promoting engagement. The co-design phase actively involved autistic and non-autistic children in iterative workshops, resulting in a multisensory collaborative play prototype. The final phase, Joint Engagement Evaluation, combined qualitative and quantitative methods, including the Joint Engagement and Reciprocity Index (JERI) and computer vision-based pose estimation using Mediapipe, to measure engagement levels during play sessions. Preliminary results indicate that structured tools and inclusive settings supported turn-taking, joint attention, and collaborative play. Future work will focus on refining the prototype and developing machine learning models to predict engagement patterns, further supporting inclusive play environments.

Keywords - Autism; Co-design; Inclusive Design; Autistic Children; Collaborative Play; Joint Engagement; Computer Vision

1. Introduction

1.1. Autism and Co-design

Co-design is a collaborative approach rooted in participatory design principles, where end-users actively contribute to the creation process, ensuring that designs meet their needs and preferences (Druin, 1999, 2002). For autistic children, co-design has proven especially valuable, as it invites them to share insights and feedback on tools intended to support their social and developmental needs (Ehn, 2008; Sanders & Stappers, 2008). In recent years, co-design has been known as an inclusive methodology in autism research (Frauenberger et al., 2017). A recent review paper (Hijab, Banire, et al., 2023) reviews various autism-centered technologies developed with input from autistic users. The paper underscores that tools created with autistic children as co-designers tend to be more effective and relevant because they reflect the children's perspectives.

In co-design with autistic children, unique challenges arise, including communication barriers and the need for adaptable engagement strategies that respect children's varying abilities and communication preferences (Frauenberger et al., 2013, 2020). Research in the Interaction Design for Children community has advanced various methods and techniques for involving children in design processes, focusing on usability and ethical considerations (Alhumaidan et al., 2018; Mechelen et al., 2019). By recognizing the importance of ethical and practical engagement methods, researchers such as Janet C. Read have introduced effective tools like the CHECk, ActiveInfo, and Tick Box Design methods (Read et al., 2017). These tools streamline the co-design process, allowing rapid collection of ideas from children and ensuring their viewpoints are integrated into the final design, while also being mindful of their comfort and agency. Working with autistic children presents additional considerations. For example, many autistic children have unique communication needs and distinct ways of engaging with design tasks (Hijab, Al-Thani, et al., 2023; Hijab et al., 2021). Studies have shown that typical participatory design methods can sometimes reinforce deficit-oriented perspectives on autism, as they may emphasize communication challenges rather than strengths (Frauenberger et al., 2011). However, strengths-based co-design practices enable autistic children to contribute meaningfully, often with support from caregivers or therapists when direct communication is difficult (Fage, 2015; Giraud et al., 2021). As co-design with autistic children evolves, it reflects a growing shift towards inclusive research, prioritizing the unique skills, insights, and interests of autistic children as co-creators in the design process.

1.2. Autism and Play

Play is widely recognized as essential to child development, enabling children to explore their environment, build social connections, and express themselves (Gray, 2017; Weisberg et al., 2013). For autistic children, however, play often manifests differently, sometimes with a focus on sensory experiences or solitary activities, which may deviate from typical expectations. In a recent systematic review, (Khatab et al., 2024) examined collaborative play with autistic children, emphasizing the richness and meaningfulness of play preferences that may appear unconventional but are deeply significant to each child. Studies by (Conn, 2015; Conn & Drew, 2017) further illustrate that many autistic children enjoy imaginative and sensory-driven activities, which reflect their unique modes of engagement and self-expression. Historically, much of the research on autistic play has contrasted it with neurotypical play, highlighting differences that were often pathologized, such as a tendency toward solitary play (Wing et al., 1977). However, recent research challenges this deficit-focused approach, advocating for a strengths-based view that acknowledges the value of autistic children's unique play styles (Gillespie-Lynch et al., 2017; Heasman & Gillespie, 2019). A recent study on outdoor and indoor play preferences among autistic children show that, when supported and understood, these play activities can foster significant development in creativity, sensory processing, and social interaction (Fahy et al., 2021). Moreover, acknowledging these play preferences aligns with neurodiversity perspectives that celebrate diversity in cognitive and social functioning, encouraging inclusive practices that support each child's strengths and interests. The importance of inclusive play environments has led to the exploration of "neurodiverse play" models, where both neurodivergent and neurotypical children engage together in play settings designed to meet diverse needs (Spiel & Gerling, 2021). Such environments are beneficial because they allow autistic children to participate in social interactions at their own pace and comfort level. However, in many traditional educational or play contexts, these inclusive opportunities remain limited, as facilities and structures are often designed around neurotypical standards (Jeanes & Magee, 2012; Stanton-Chapman & Schmidt, 2017).

1.3. Autism and Joint Engagement

Joint engagement, a social and interactional concept, is fundamental in developing social communication skills and building shared experiences between individuals (Ruble & Robson, 2007). For autistic children, joint engagement is particularly significant, as it can create opportunities for them to connect with others in a way that feels natural and comfortable. Engagement in child interactions has been defined through various approaches, with some studies using coding schemes based on gaze, actions, and emotional states (Pan et al., 2023). The concept of joint engagement builds on these definitions, referring specifically to a shared focus on an object or activity that involves both participants' attention and participation. It is frequently measured through indicators such as eye gaze, latency in responding to another's speech, and gaze duration (Adamson et al., 2004). For autistic children, developing joint engagement can strengthen language skills, build social communication abilities, and provide a foundation for peer interactions (Adamson et al., 2004). Studies emphasize that when joint engagement is facilitated within supportive play environments, autistic children demonstrate improved social outcomes, including better communication and relationship-building skills. In therapeutic and everyday settings, joint engagement is a goal

for supporting social interactions. (Pan et al., 2023) highlight that, particularly for children with developmental disorders, joint engagement can serve as a gateway to improved language outcomes and stronger social bonds. Integrating joint engagement into play-based activities for autistic children allows them to build skills such as turn-taking, symbolic play, and collaboration, which are foundational to social interaction. Moreover, activities that foster joint engagement align with the neurodiversity perspective, emphasizing each child's strengths and preferences in building social skills.

1.4. Problem Statement

Given the increasing awareness of the unique ways autistic children engage with their environment, particularly in social and play-based contexts, there is a pressing need to develop tools that foster inclusive and collaborative interactions. Traditional approaches to play for autistic children often emphasize deficits, overlooking the strengths and preferences that can be harnessed to create meaningful engagement opportunities. This paper addresses the challenge of how to design an interface that encourages collaborative and inclusive play for autistic children while respecting their individual needs and communication styles. By involving autistic children as co-designers, this project aims to create a prototype that reflects their insights and preferences, ensuring that the final design is both accessible and empowering. Furthermore, this paper will examine the levels of joint engagement achieved by autistic children while interacting with the co-designed prototype, providing insights into how such tools can support meaningful social interactions. The interface will be evaluated with both autistic and non-autistic children, focusing on its effectiveness in promoting joint engagement, social interaction, and feedback from the children themselves. This approach not only prioritizes the voices of autistic children but also advances a strengths-based perspective that values their contributions and experiences in shaping tools designed for their use. This paper outlines the methodology and preliminary findings of a project designed to create engaging play experiences aligned with autistic children's perspectives and preferences, aiming to foster joyful, socially significant interactions.

2. Research Methodology and Approach

This project's methodology is structured into three main phases as shown in : Contextual Inquiry, Co-Design, and Joint Engagement Evaluation. Each phase serves a unique purpose, from gathering foundational insights on collaborative play to developing and testing a prototype specifically designed for autistic children.

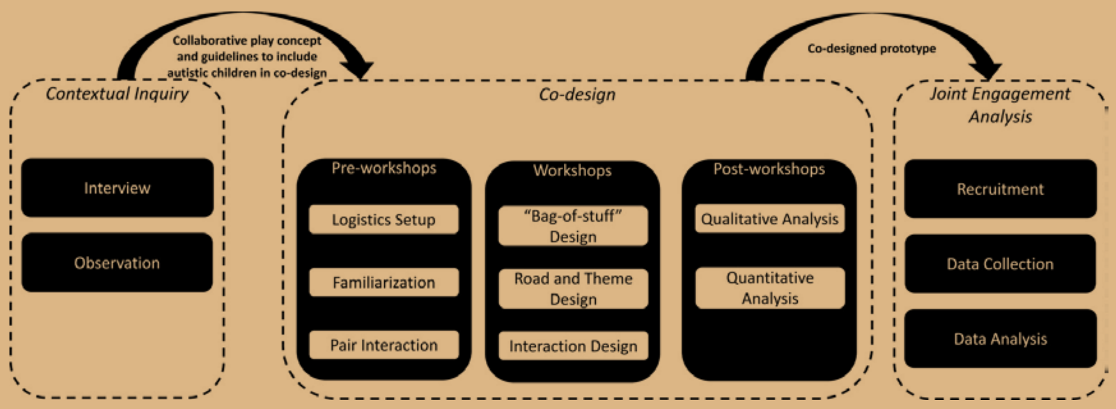

Figure 1. Project Methodology

2.1. Contextual Inquiry

The contextual inquiry phase focused on understanding the tools, technologies, and behavioral patterns involved in collaborative play among autistic children in classroom settings (Holtzblatt & Beyer, 1997). Conducted in a center for children with disabilities and an inclusive school in Qatar, the inquiry involved interviews with teachers, therapists, and parents, as well as observation sessions of autistic and non-autistic children in various play contexts. This phase aimed to identify both challenges and opportunities in fostering collaborative play, collecting data through semi-structured interviews and thematic analysis (Clarke & Braun, 2017). A total of 45 interviews were conducted with a variety of specialists, including teachers, speech and language therapists, occupational therapists, psychologists, and physiotherapists. Additionally, 48 observation sessions were completed, capturing activities such as sports, art, and music sessions. Observation data were coded into four main themes—Collaborative Play, Coordinated Activity, Potential for Collaboration, and Collaborative Activity—which provided insight into the children's interactions and informed the co-design phase. Ethical considerations included obtaining consent and assent, with participants assigned coded identifiers to ensure confidentiality.

2.2. Co-design

Building on the findings from the contextual inquiry, the co-design phase actively involved autistic and non-autistic children in the prototype's development. This phase was organized into three sub-phases: Pre-Workshops, Co-Design Workshops, and Post-Workshops. The pre-workshops focused on familiarizing children with the environment, the research team, and the design process. Children participated in 10 familiarization sessions, where they were observed in free play settings to understand their preferences. Based on these interactions, children were paired with their favorite toys and engaged in structured play sessions designed to foster comfort and social bonds. In the co-design workshops, children took part in three specific activities—Bag-of-Stuff Design, Road and Theme Design, and Interaction Design. In Bag-of-Stuff Design, children selected sensory features, shapes, and colors to create objects that reflected their preferences. During Road and Theme Design, they constructed roads and themes for the collaborative play prototype, which helped instill a sense of ownership over the prototype. Finally, the Interaction Design phase introduced "obstacles" that encouraged collaborative problem-solving and engagement, fostering turn-taking and joint attention. These activities were designed based on insights from specialists and previous observations to promote inclusive play.

The post-workshops phase consisted of evaluation sessions, where each pair of children engaged with the final co-designed prototype in a 30-minute free play session. Qualitative and quantitative data were gathered on collaborative play behaviors, child-child and child-toy interactions, and key skills such as joint attention and turn-taking. Video recordings from this phase were analyzed for insights into the effectiveness of the prototype in supporting meaningful social interactions.

2.3. Joint Engagement Evaluation

The final phase aimed to quantitatively measure joint engagement levels using the Joint Engagement and Reciprocity Index (JERI) and computer vision-based pose estimation. JERI, a coding scheme for assessing joint engagement quality and quantity, was employed to capture the nuances of how children shared attention with peers and reciprocated within interactions (Adamson et al., 2008). Specifically, JERI differentiates between supported and coordinated joint engagement, which allowed researchers to assess the prototype's effectiveness in fostering social connection. The children's engagement levels were categorized as No Engagement, Low Engagement, Medium Engagement, and High Engagement, based on a 1 to 7 Likert scale. The experimental setup involved an Intel RealSense D455 depth camera and two Canon RGB cameras positioned to capture multiple views of the room. This setup ensured comprehensive coverage of the children's interactions with the prototype. Video recordings were segmented into 5-second clips, resulting in over 5,699 fragments, which were annotated by two trained raters to ensure inter-rater reliability, achieving an intraclass correlation coefficient of 90%. Disagreements were resolved through consensus. To complement JERI analysis, computer vision techniques using the Mediapipe library were applied to estimate the children's body and hand key points. This data was used to create feature vectors that will aid in training machine learning models to recognize joint engagement patterns.

3. Preliminary Results

The results of this study provide critical insights into the design and evaluation of collaborative play tools for autistic children. By systematically analyzing data from three distinct phases—Contextual Inquiry, Co-Design, and Joint Engagement Evaluation—this section highlights the interplay between environmental factors, children's preferences, and engagement levels. Each phase contributes uniquely to understanding and enhancing collaborative play, offering valuable implications for designing adaptable tools that cater to diverse neurodivergent needs and broader contexts. The findings not only inform prototype development but also lay the groundwork for extending these tools to other settings and groups, fostering inclusivity and interaction.

3.1. Contextual Inquiry

The contextual inquiry phase (Hijab, Khattab, et al., 2024) uncovered essential insights into factors influencing collaborative play for autistic children, informed by semi-structured interviews and observations.

- **Semi-structured interviews:** Six primary themes emerged from the thematic analysis of interviews with teachers, therapists, and parents, organized by the "5W-H model." The themes were Actors (who participates in collaborative play), Location (settings like school and public spaces), Purpose (social, academic, and daily living skills), Type of Technology (analog vs. digital tools), Sense (sensory modes like touch and visual cues), and Process (the role of interaction, challenges, and role changes during play). Teachers highlighted collaborative play's role in supporting turn-taking, communication, and social skills. Parents provided additional context about play in various settings, including home and public spaces, highlighting the importance of real-life contexts for skill practice.
- **Observation sessions:** Observational data captured varied interaction levels across school and center settings, categorized as Collaborative Play, Coordinated Activity, Potential for Collaboration, and Collaborative Activity. Collaborative play, most notably observed at school, showed children developing turn-taking and communication skills with guidance from teachers. The school environment facilitated higher engagement, with structured activities promoting interaction and shared goals. In contrast, the center's sessions primarily revealed parallel play, as children tended to engage individually with toys, suggesting that structured guidance may be needed to foster collaborative play.

3.2. Co-design

The co-design phase (Hijab, Al Aswadi, et al., 2024), comprising pre-workshops, co-design workshops, and post-workshop evaluation, yielded a collaborative play prototype, shaped by children's preferences and interactions.

- **Group formation and toy preferences:** Children were grouped based on observed toy preferences, resulting in tailored pairings that fostered compatibility. Through the familiarization phase, children revealed preferences that guided grouping and prototype design elements, such as "press-to-play" and puzzle-based activities.

- **Collaborative play tool design:** The "Bag-of-stuff" included sensory-rich toys and elements reflecting children's choices in categories like color, shape, and texture. For example, center children preferred animal shapes, while school children leaned towards car themes, resulting in unique sensory features for each location. The road and theme design phase allowed children to construct their play pathways, engaging deeply with choices around obstacles that encouraged interaction and collaboration. By accommodating both solitary and collaborative preferences, the design provided flexibility for varying engagement styles.
- **Interaction and engagement patterns:** Interaction design focused on joint activities that required two children to work together, such as moving obstacles on a road or assembling puzzle pieces. Observations revealed that children transitioned from solitary to parallel play, ultimately reaching collaborative engagement with guidance from specialists. Tools like "open-the-gate" or "clear-the-way" supported turn-taking and cooperative problem-solving, essential skills for collaborative play.

3.3. Joint Engagement Evaluation

The analysis of joint engagement using the JERI score and Mediapipe data offered quantifiable insights into engagement levels.

- **JERI scale data:** The JERI analysis revealed that Low Engagement was predominant across groups, though certain groups displayed notable instances of Medium and High Engagement. Several groups exhibited more active interactions, suggesting that specific group dynamics or activity types may foster engagement. These findings indicate potential pathways for refining activities to increase engagement, particularly by focusing on elements that contributed to Medium Engagement levels in select groups.
- **Mediapipe data:** The data were extracted from Mediapipe revealing 146,192 frames. Yet, some of the frames include only data of one child. After data cleaning to ensure only complete frames were analyzed, 92,803 frames remained, representing reliable engagement interactions.
- **Mapping JERI to movement patterns:** This preliminary analysis provides a foundation for a machine learning model that could predict engagement levels based on body movement data. Mapping JERI scores to Mediapipe data revealed that groups with higher engagement scores also demonstrated more complex body movements, suggesting a correlation between physical activity and engagement levels. Groups with predominant Low Engagement showed fewer dynamic movements, indicating a possible link between reduced physical engagement and lower interaction quality. Patterns identified in the JERI-Mediapipe mapping demonstrate how movement complexity varies with engagement scores, offering a nuanced understanding of how children's physical interaction with the play tool corresponds to their engagement quality.

4. Discussion

This study integrates a structured methodology—contextual inquiry, co-design, and joint engagement evaluation—to create collaborative play tools specifically for autistic children. These tools, grounded in participatory and co-design principles (Druin, 1999; Sanders & Stappers, 2008), reflect the children's preferences and communication styles, demonstrating the potential to address similar needs in other neurodiverse populations. The inclusion of tools like the Picture Exchange Communication System (PECS) to involve non-verbal participants (Hijab, Al-Thani, et al., 2023) underscores the adaptability of the methodology for children with diverse communication needs, such as those with Down syndrome or speech delays. Expanding this framework to address broader sensory and cognitive profiles, including those with sensory processing disorders or ADHD, can enhance its utility across multiple contexts. The approach also aligns with strengths-based perspectives, moving away from deficit-oriented views of neurodivergence (Frauenberger et al., 2013; Gillespie-Lynch et al., 2017). By emphasizing the unique skills and preferences of children, the methodology supports the creation of tools that are both inclusive and empowering. The design of inclusive play environments, where neurodivergent and neurotypical children interact meaningfully, further aligns with neurodiverse play models proposed by Spiel and Gerling (2021). Such environments enable social connection while respecting each child's pace and style, offering opportunities for mutual learning and collaboration.

Additionally, the use of joint engagement evaluation, combining qualitative and quantitative data (Adamson et al., 2008; Pan et al., 2023), demonstrates a scalable model for examining engagement patterns. These methods could be adapted to study other populations and settings, such as mixed-neurotype classrooms or therapy sessions, ensuring that tools are refined to promote inclusivity and interaction.

4.1. Implications

The findings from this study highlight practical and meaningful insights for educators, therapists, and researchers aiming to support neurodivergent children through collaborative play.

- **For Educators:** The findings emphasize the importance of structured yet adaptable activities in supporting neurodivergent students. The modular design of the "Bag-of-stuff" prototype, which reflects the principles of co-design (Ehn, 2008), allows educators to tailor activities to diverse needs. For instance, tactile and auditory elements can support sensory-sensitive students (Conn, 2015; Conn & Drew, 2017), while simplified tasks are effective for children with cognitive delays. By fostering turn-taking, communication, and shared goals, educators can create inclusive learning environments, enabling neurodivergent and neurotypical students to engage meaningfully with one another (Stanton-Chapman & Schmidt, 2017).
- **For Therapists:** Therapists can use the co-design principles demonstrated in this study to craft interventions that align with individual needs and preferences. By incorporating communication strategies like PECS (Hijab, Al-Thani, et al., 2023) and movement-based activities, therapists can enhance engagement and interaction. The findings that complex movements correlate with higher engagement levels (Pan et al., 2023) suggest integrating physical activities into therapy to promote social skills like turn-taking and collaboration. Such strategies align with the neurodiversity perspective, emphasizing strengths and individual preferences over deficits (Gillespie-Lynch et al., 2017).

- **For Researchers:** This study's integration of qualitative themes, such as sensory modes and processes (Clarke & Braun, 2017), with quantitative tools like the JERI scale (Adamson et al., 2008) and Mediapipe data offers a replicable model for engagement analysis. Researchers can adapt these methods to study other neurodiverse populations, such as children with ADHD, to identify how engagement patterns vary across contexts. The methodology also provides a foundation for creating adaptive play tools that adjust in real time, informed by a combination of user input and machine learning models (Holtzblatt & Beyer, 1997). Furthermore, examining inclusive play models (Spiel & Gerling, 2021) can advance research on fostering neurodiverse interactions in educational and community settings.

4.2. Limitation and Future Work

The methodology utilized in this study focusses on co-design that engage both autistic and non-autistic children in the design process but also revealed certain limitations. The insights generated, while valuable, are derived from a single project context, limiting the broader generalizability of the findings. Although the study spanned two distinct locations in Qatar, allowing for observations in different settings, the applicability of the methodology across more diverse environments and populations remains untested. Future work will focus on refining and enhancing the co-design methodology by critically evaluating the structure of co-design sessions. This includes ensuring activities are inclusive and tailored to accommodate diverse sensory needs, communication styles, and levels of participant agency. Adjustments will aim to make the methodology more flexible and adaptable to a wider range of participants and contexts while preserving its core emphasis on genuine collaboration. Additionally, future research will extend the application and evaluation of the co-designed prototypes to other subsets of the autism community. This will involve assessing the tools' effectiveness and adaptability in varied settings, contributing to a deeper understanding of how co-design principles and outcomes can be applied broadly. These efforts are essential for advancing inclusive design practices and ensuring that co-design methods and tools are accessible and impactful across different contexts and populations.

5. Conclusion

This study demonstrated the potential of a co-design approach in fostering collaborative play among autistic children, using structured, interactive tools to enhance engagement. Through contextual inquiry, co-design workshops, and engagement assessment, we identified effective methods for promoting turn-taking and joint attention. Observations showed that structured settings and tailored play tools contributed positively to engagement levels, with Mediapipe and JERI score mapping indicating a correlation between physical interaction and sustained engagement. Future work will focus on finalizing the joint engagement evaluation and building a machine learning model to help specialists better understand joint engagement in autistic children's play, advancing our ability to support inclusive, engaging play environments.

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A Federated Learning-Based Virtual Interpreter for Arabic Sign Language Recognition in Smart Cities

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Abstract: Arabic Sign Language (ASL) exhibits structured grammar and syntax, necessitating adherence to these rules in automated sign language generation for people with disabilities. Hence, the effective generation of sign language relies heavily on using 3D virtual signers. This paper presents a groundbreaking framework that employs federated learning to develop a virtual interpreter for ASL, aimed at enhancing accessibility and communication for the deaf community in smart cities. The proposed paradigm establishes a baseline to facilitate the creation of innovative applications that generate contextually and grammatically accurate sign language interpretations. By employing federated deep learning, the framework maintains user privacy while allowing for continuous improvement of the interpreter's performance. This paradigm aims to promote inclusivity and assistive technologies by integrating sign language into urban technological solutions.

Keywords: Arabic sign language; Federated deep learning; Accessibility; Avatar; Smart city.

1. Introduction

Since Smart cities rely on Internet of Things (IoT) sensors for data collection and support a range of applications across fields such as public services, resource management, and communication (Zheng et al., 2022). Additionally, smart cities offer effective solutions for key challenges such as IoT development (Li et al., 2020), healthcare (Ghazal et al., 2021), transportation (Ushakov et al., 2022), and communication systems (Guan et al., 2018). Throughout this extensive data exchange process, sensors produce vast amounts of data. Deaf and Hard of Hearing (DHH) individuals who primarily use sign language often consider themselves part of a linguistic and cultural minority, as they lack full access to the same linguistic resources available to hearing individuals (Bramwell et al., 2000).

Traditional sign language interpretation services and accessibility measures are usually not able to meet the needs of DHH individuals, especially in non-Western regions (Othman et al., 2024). In smart cities, AI-powered signing avatars present a promising solution to bridge this accessibility gap. These avatars can enhance the inclusion and visibility of sign language within digital content and public services, creating more accessible urban environments.

By integrating signing avatars in smart city infrastructure, DHH individuals can experience improved communication access in areas like transportation, healthcare, and public information, reinforcing the cultural and linguistic identity of Deaf communities globally.

Federated learning is a decentralized approach to machine learning that enables multiple devices or entities to collaboratively train a shared model while keeping their data locally stored Kairouz et al., 2021). Using

avatars in smart cities that leverage federated learning enables them to become more adaptive to user needs while maintaining user privacy. This way each avatar functions locally on a user's device or within a specific setting, such as a public kiosk or a healthcare center, and works exclusively with its own unique data. For instance, avatars serving DHH users can process local information to respond to user queries, interpret sign language, or offer guidance in navigation, all while storing this sensitive interaction data locally.

In this paper, we introduce a preliminary model for a realistic Arabian avatar that interprets Arabic Sign Language (ArSL) in smart city ecosystems, preserving efficiency, accuracy, privacy, and security. The FL-based avatar eliminates the need to share raw data with a central server. Instead, they process local data to learn and adapt, updating their models to align with each user's preferences and needs. Each avatar periodically sends model updates, such as updated weights or features, to a central aggregator. The aggregator combines these updates to refine a global model, which is then distributed back to the avatars. This enables them to incorporate the collective knowledge of all users while ensuring that personal information is never exchanged. This collaborative technique allows each avatar to improve in accuracy and contextual awareness over time. For example, an avatar serving DHH users in a hospital can learn how to interpret medical instructions, whereas an avatar in a transportation hub can enhance its ability to provide real-time navigation help. As a result of the federated learning process, avatars can gain knowledge in a variety of circumstances, benefiting from experiences in multiple environments.

The remaining part of this paper is organized as follows: Section 2 highlights the key benefits of employing FL for ArSL, Section 3 reviews the related avatar-based works, Section 4 presents the structure of proposed ArSL avatar within smart cities, Section 5 illustrates the avatar's communication framework, Section 6 discusses the experimental simulation results, and Section 7 concludes this work.

2.Benefits of Federated Learning for ArSL in Smart City

Adopting the federated learning paradigm for Arabic sign language in smart cities provides numerous advantages, including enhanced performance, accessibility, real-time adaptation, strengthened privacy, scalability, and collaborative learning. Figure 1 illustrates the advantages of using FL-based avatars in smart cities, which are further discussed in the following subsections.

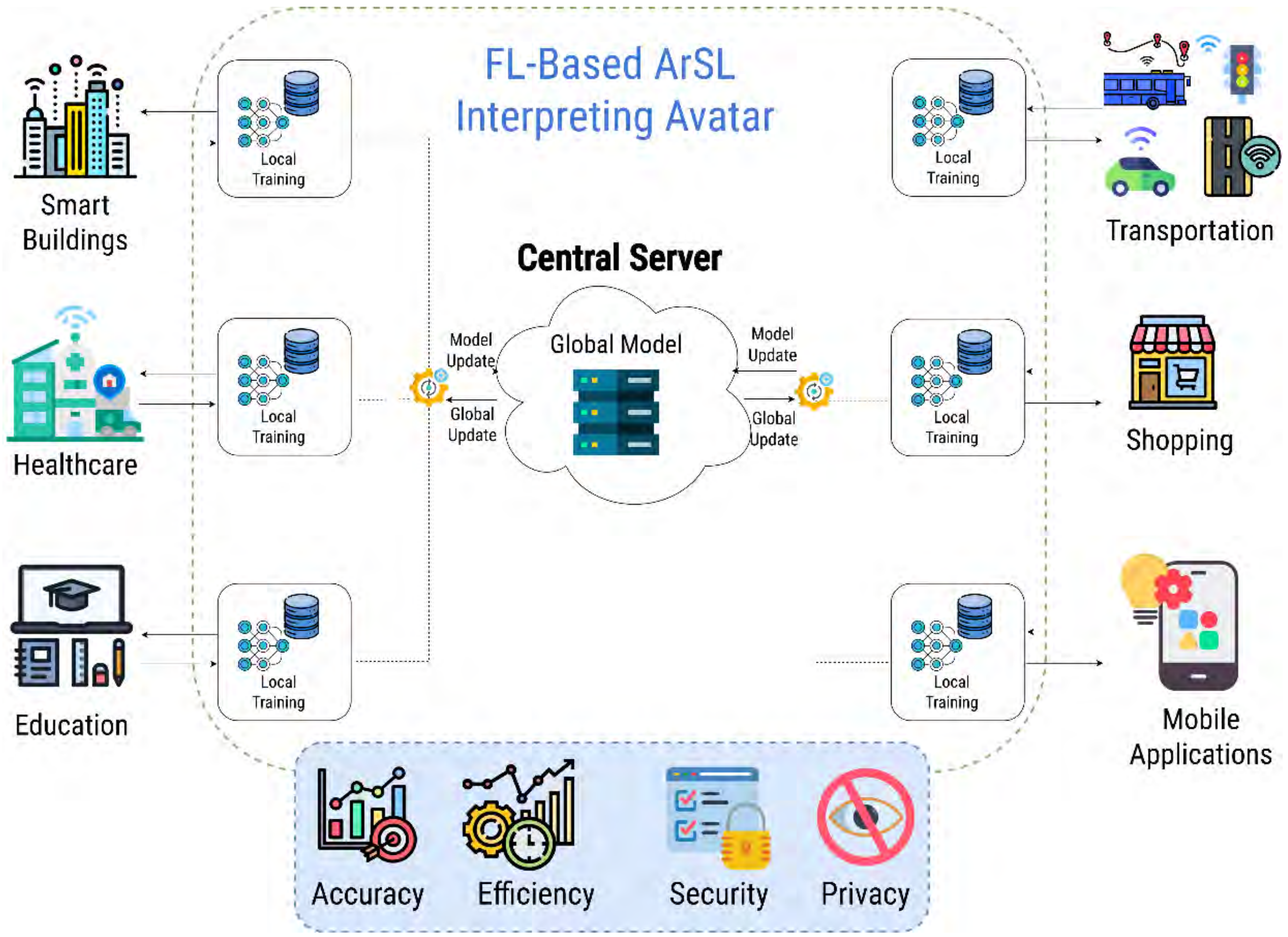

Figure 1. A generic federated learning paradigm within smart cities.

2.1. Enhanced Interpretation Accuracy

This refers to the avatar's ability to provide responses that are relevant, precise, and contextually appropriate for each user's needs (Garcia et al., 2023). An accurate avatar can understand user intent, whether interpreting sign language, offering emergency assistance, or helping with city navigation. Contextual adaptation allows the avatar to customize its responses based on the user's location, recent interactions, or unique needs. Federated learning improves accuracy by enabling the avatar to learn from local interactions across various devices rather than centralizing data (Pandya et al., 2023). However, several issues can significantly impact the effectiveness of various applications in smart cities, such as traffic management and public safety. Factors like data heterogeneity, sparse data availability, variable client engagement, and resource constraints of IoT devices contribute to these challenges. Inconsistent data from diverse sources, combined with dynamic environments that can change rapidly, often leads to non-IID data distributions and gaps in training data, resulting in models that do not accurately reflect city conditions.

The proposed FL-based avatar aims at addressing these challenges by enhancing data integration through standardizing inputs from various sources and implementing an adaptive decentralized learning technique that adjusts models based on local conditions. Additionally, it facilitates hierarchical clustering of clients based on geographical regions or services, allowing for more targeted model training. Furthermore, it utilizes robust aggregation techniques to enhance the resilience of the global model, ensuring it remains accurate despite the diverse and dynamic nature of data sources within smart cities. Additionally, the avatar's ability to recognize and accurately interpret Arabic dialect enhances its overall accuracy by improving its responsiveness to the unique needs of the Arabic-speaking deaf community. This continuous improvement process enhances the model's understanding, resulting in more accurate responses. Real-time updates enable the avatar to react to changing situations, such as providing timely weather or traffic updates based on actual city conditions, thereby boosting guide accuracy.

2.2. Improved Real-Time Adaptation and Accessibility

The goal is to deliver fast, resource-efficient, and responsive assistance to users. This is accomplished by integrating edge computing with federated learning, enabling avatars to function with low latency, reduced bandwidth consumption, and optimized resource utilization. By processing data on local edge devices, such as nearby servers or user devices, the FL-based avatar avoids delays from central cloud processing and enables faster responses and real-time feedback. Data on local conditions, such as traffic or public transit schedules, is instantly accessible, allowing the avatar to quickly provide the fastest route home if needed. However, communication overhead may arise in such scenarios due to the potentially large size of model updates sent to the central server, particularly when dealing with complex models. Additionally, a large number of clients can create overhead, as each client sending its updates may significantly increase network traffic. Data heterogeneity may also contribute to this issue, as variations in data across clients can lead to differences in update sizes and frequencies, complicating the aggregation process.

The proposed avatar addresses these challenges and achieves high efficiency by minimizing the size of model updates (e.g., weights and gradients) sent to the central server, thereby substantially reducing bandwidth requirements. Additionally, the use of asynchronous FL (Xu et al., 2023) allows updates from clients to be processed individually while reducing waiting time and preventing network traffic. This approach to selective data sharing ensures the avatar remains lightweight and efficient while leveraging shared user experiences across the city.

Federated learning thus makes it possible for ArSL models to be continuously improved through local adaptation and distributed user feedback. For those who use sign language, this creates more inclusive smart city settings that improve interaction and communication. Moreover, the decentralized nature of federated learning allows the model to adapt to regional dialects, user preferences, and specific needs in real time, making it more effective in diverse urban settings.

2.3. Maintain Privacy and Security

Federated learning's capacity to maintain privacy is one of its main benefits. This is achieved by using FL and edge computing among dispersed avatars in smart cities. This setup allows avatars to process and learn from local data within their designated areas, ensuring that sensitive information remains within the local environment rather than being transmitted to a central server. Information leakage, however, is a major concern in smart cities that depend on FL systems since hackers may use strategies like model poisoning or data poisoning to take advantage of vulnerabilities. Additionally, algorithms such as gradient descent can leak sensitive user information, further exposing the FL ecosystem to potential attacks (Pandya et al., 2023).

The proposed FL-based communication paradigm enables distributed avatars with privacy-preserving techniques that only share anonymized model updates rather than raw data, thus reducing data exposure. Moreover, encrypted communication channels between avatars protect all interactions, while decentralized data management allows each avatar to control data locally, enhancing privacy. This technique not only respects privacy rules, but it also preserves user trust by assuring that sensitive data is handled securely on the local level. Furthermore, the proposed FL framework maintains security by restricting the impact of potential attacks to specific areas rather than affecting the entire system, where regular updates and security patches can be given directly to each avatar, assuring their continued protection without relying on a central system for critical security functions.

3. Related Work

Various avatar systems have been developed to enhance accessibility in education, communication, and real-time interactions for individuals with disabilities, particularly within the Arabic-speaking community. These avatars vary in functionality, focus, and underlying technologies. Only a few of these avatars are explicitly designed to address communication issues with people who are deaf or hard of hearing.

Mind Rockets (Mindrockets, 2024) offers avatars for translating text into Arabic sign language and other sign languages. These avatars are lightweight and easily integrated into websites, focusing on accessibility for the deaf and other individuals with disabilities, such as those with Attention-Deficit/Hyperactivity Disorder (ADHD) or dyslexia. Mind Rockets avatars' primary advantages are their broad covering of disabilities, ease of integration, and compatibility with websites, mobile apps, and other digital platforms. It can only translate text to signs, though.

Eshara avatar system (Eshara, 2024) is another significant advancement in ArSL translation. This system translates Arabic sign language into written or spoken text and vice versa scaling across multiple dialects. Eshara focuses on bidirectional communication, making it not only capable of translating sign language gestures into text but also interpreting text into sign language via an animated avatar. Only a web application is now available for this avatar system, which is still relatively new.

BuHamad avatar (Othman & El Ghoul, 2022) is a Qatari innovation that translates text into Qatari sign language. With its culturally significant attire (Ghutra and Thobe) and highly realistic animations, the avatar resonates deeply with the local deaf community. It is supported by a sophisticated cloud-based architecture that enables efficient real-time rendering even in low-bandwidth environments. It prioritizes cultural relevance and accessibility, serving as a bridge between the hearing and deaf communities within Qatar. Its architecture includes components for translating Arabic text into sign language animations and a database of annotated signs and sentences. Its realistic design, cloud efficiency, and cultural integration make it remarkable. The fact that this avatar is only available in the Qatari dialect, with possible scalability issues for other Arabic-speaking regions, is one of its primary limitations.

Our proposed FL-based avatar provides notable advancements over existing systems, including enhanced privacy, greater dialect flexibility, improved accessibility, and better adaptability across various sectors. Unlike traditional centralized systems that process user data on cloud platforms and expose sensitive information, our avatar is trained on decentralized data through federated learning. This ensures robust privacy preservation while constantly improving translation capabilities. It is also designed to interact seamlessly across various platforms and sectors within smart cities, setting a new standard for inclusive communication and accessibility for the Arabic-speaking deaf community. In comparison, Eshara, BuHamad, and Mind Rockets offer strong localized solutions but may lack the broad adaptability and privacy aspects provided by our avatar. It is also designed for adaptive and context-aware interactions, as it customizes its appearance based on the specific sector (e.g., medical, customer service, transportation). This ensures that our avatar is not only linguistically correct but also context-appropriate. Existing systems employ static designs that lack this sector-specific adaptability, reducing their effectiveness in diverse smart city applications.

	BuHamad	Mind Rockets	Eshara	FL-Based Avatar
Target Audience	Qatari Deaf Community	General & Arabic Deaf Community	Arabic Deaf Community	Arabic Deaf Community
Dialect Support	Limited to Qatari Sign Language	Multiple dialects and languages	Limited dialect support	Diverse Arabic dialects and idioms
Cultural & Regional Relevance	Limited to Qatari Sign Language	Multiple dialects and languages	Limited dialect support	Diverse Arabic dialects and idioms
Privacy & Security	Strong cultural relevance	Limited cultural customization	Limited cultural relevance	Adaptive design, region-specific uniforms
Facial Expressions & Gestures	Fixed avatar design for Qatari context	Fixed avatars adaptable to various platforms	Customizable avatars	Adaptive avatars based on sector
Platform Compatibility	Realistic 3D gestures	Standard sign language gestures	Standard sign language gestures	Expressive facial features and nuanced gestures

Table 1. A summary of FL-based avatar compared to the related ArSL avatars.

4. The Avatar Structure

The proposed FL-based framework involves a realistic Arabian avatar created to facilitate ArSL translation in smart city ecosystems with a focus on efficiency, accuracy, and privacy. Translating ArSL provides unique issues due to its complicated linguistic structure and the limited resources accessible for ArSL linguistics, particularly when dealing with varied Arabic dialects and regional idioms. Existing avatar-based systems frequently rely on a crude word-by-word translation technique, which fails to convey the nuances of actual language expression required for ArSL and lacks proper dialect support (Othman & El Ghoul, 2022). To address these challenges, the avatar in this work utilizes a federated learning approach, enabling it to enhance its translation abilities by training on diverse data sources while preserving privacy. This aims at improving the ability to recognize and accurately interpret various Arabic dialects, hence increasing responsiveness to the specific demands of the Arabic-speaking deaf community.

The potential of FL-based avatar extends to a variety of smart city sectors, including public transportation, healthcare, customer service, education, and more. Where it can facilitate more inclusive and accessible interactions for deaf people. In these sectors, the avatar's appearance will adapt to suit the context, enhancing reliability and realism in communication. For instance, in healthcare settings, the federated learning-based avatar will wear a medical uniform; in customer service environments, it will be dressed in formal attire; and for transportation, a casual uniform will be used. This adaptive design aims to offer a more immersive and respectful experience for users across various applications.

Several technical problems must be overcome to ensure that our proposed avatar can meet the needs of real-time and realistic sign language translation. The avatar must demonstrate lifelike animation, including expressive facial features and natural gestures, which are vital for conveying subtleties and emotions, as shown in Figure 2. Furthermore, the FL-based avatar is intended to work seamlessly across a variety of platforms, including mobile phones, web browsers, and smartwatches, while preserving performance on low-speed internet connections and limited graphical capabilities. Cross-platform compatibility and responsive real-time capabilities are required for successful deployment within the smart city framework.

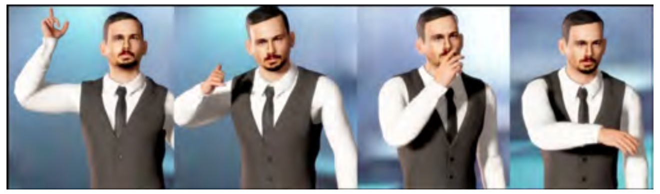

Figure 2. A demonstration of Avatar's expressive body features.

The proposed FL-based avatar provides a promising improvement in avatar-based sign language translation by combining advanced linguistic modeling and federated learning, addressing the objectives of privacy, dialectic correctness, and efficient operation that smart city applications require. This FL-based ArSL paradigm aims to set a novel standard for accessible communication by fostering a more inclusive urban environment for the Arabic-speaking deaf community. To animate the 3D avatar, we use two different components that improve its visual depiction, as follows:

Skeleton-Based Animation.
We present a skeleton structure for the FL-based ArSL avatar, which allows for exact control of bodily movements. We meticulously skinned the avatar's mesh to match the stiff transformations of each bone in the skeleton. This technique ensures that when the rig is adjusted, the matching mesh deforms smoothly, allowing for natural body and hand gestures that are essential for efficient communication in ArSL systems.

Vertex Morphing Animation.
For detailed facial animations, we utilize vertex morphing. Figure 3(a) illustrates how to produce expressive face expressions by altering the placements of specific vertices within the avatar's geometry. Specific mathematical functions can be used to save or modify the new position of each vertex. Because of its high resource requirements, this technology is only used for creating sophisticated facial movements. Figure 3(b) displays the 3D object representing the construction of the avatar's face.

The proposed baseline requires a set of sophisticated tools and services to help with the avatar's animation. This design will enable developers to quickly integrate the FL-based avatar into various applications while offering the capability for converting written text into interpreted Arabic sign language.

Figure 3. Avatar's front expression (left) and 3D face (right).

5. The Federated Communication Framework

In this work, the FL-based ArSL Avatar works within a decentralized communication framework architecture, with each sector using its avatar. Each avatar is provided with a local dataset and a local model, allowing it to effectively interact with the deaf community while continuously improving its performance via a federated learning strategy.

5.1. Federated Learning Process

Figure 4 shows the federated learning process. Each sector's avatar i has access to a local dataset Di containing interaction data with local deaf users. The avatar uses this dataset to train its local model, Mi. The local training process can be structured as follows:

$$M_i^{(t+1)} = M_i^{(t)} - \eta \nabla L(M_i^{(t)}, D_i) \quad (1)$$

where:

- $M_i^{(t+1)} = M_i^{(t)} - \eta \nabla L(M_i^{(t)}, D_i)$
- η is the learning rate.
- L represents the loss function computed on the local dataset D_i.

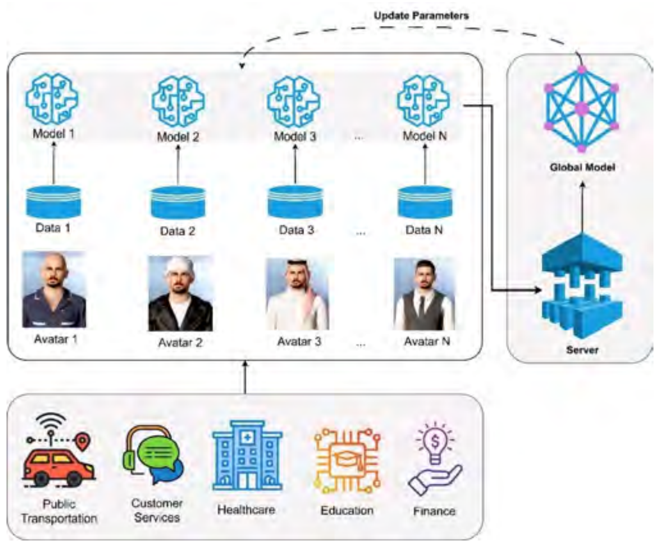

Figure 4. Avatar communication in federated deep learning.

After completing the local training, the avatar generates a model update VM_i, which captures the changes made to its parameters:

$$\nabla Mi = M_i^{(t+1)} - M_i^{(t)} \quad (2)$$

At the end of a predefined period (e.g., daily), all local model updates from the avatars in various sectors are sent to a central server for aggregation. The aggregation process can be represented as:

$$M^{(t+1)} = M^{(t)} + \frac{1}{N}\sum_{i=1}^{N} \nabla Mi \quad (3)$$

where:

- $M^{(t)}$ are the global model parameters at iteration t.
- N is the total number of avatars (local models) participating in the update.

The aggregated update is then used to refine the global model M at the server:

$$M^{(t+1)} = M^{(t)} + \alpha(M^{(t+1)} - M^{(t)}) \quad (4)$$

where ∂ is a hyperparameter that determines the contribution of the aggregated update to the global model. After the global model has been updated, the new parameters are distributed back to each avatar, allowing them to initialize their local models with the improved global knowledge. This process is done iteratively, with each avatar continuously learning from its interactions with local deaf users, updating its local model, and contributing to the global aggregate. This results in a steadily evolving avatar system capable of better understanding and interpreting Arabic sign language. The federated learning approach allows the FL-based Avatar in smart cities to maintain users' privacy while enhancing communication capabilities. By exploiting local data for personalized learning and collecting model updates regularly, avatars may easily adapt to the demands of the deaf community in a variety of industries, resulting in improved communication and inclusion in smart urban environments.

5.2. Federated Learning Infrastructure in Real-World Scenarios

Implementing the federated learning paradigm in real-world applications requires a robust, scalable infrastructure that is tailored to the specific needs of each sector while adhering to common principles. FL is based on edge computing, with intelligent edge nodes equipped for local training and inference, as shown in Figure 5. These nodes use modern hardware, such as CPUs, GPUs, and specialized processors such as TPUs, to do complex machine-learning tasks on-site, lowering latency and increasing responsiveness (Duan et al., 2023). For example, IoT-enabled medical equipment and localized servers in healthcare allow for sensitive patient data training, whilst onboard computer units in cars provide real-time processing of traffic and sensor data in public transit. Similarly, devices such as tablets and laptops when combined with institutional servers provide personalized learning in education, while branch servers, ATMs, and consumer devices enable localized FL models in customer service and finance.

High-capacity storage systems are critical for managing massive, dispersed datasets across different industries, but data privacy is protected by keeping it localized at edge nodes (Salh et al., 2023). Secure on-premises storage solutions are critical, including encrypted Solid-State Drives (SSDs) for medical records, localized storage for traffic and passenger data, distributed academic datasets from learning management systems, customer interaction logs for service models and encrypted financial data for fraud detection. Furthermore, efficient and secure communication networks, such as 5G, fiber-optic, or Wi-Fi, are required for continuous model updates between edge nodes and central aggregation hubs (Yang et al., 2023). These networks allow nodes to safely communicate model parameters while maintaining data privacy.

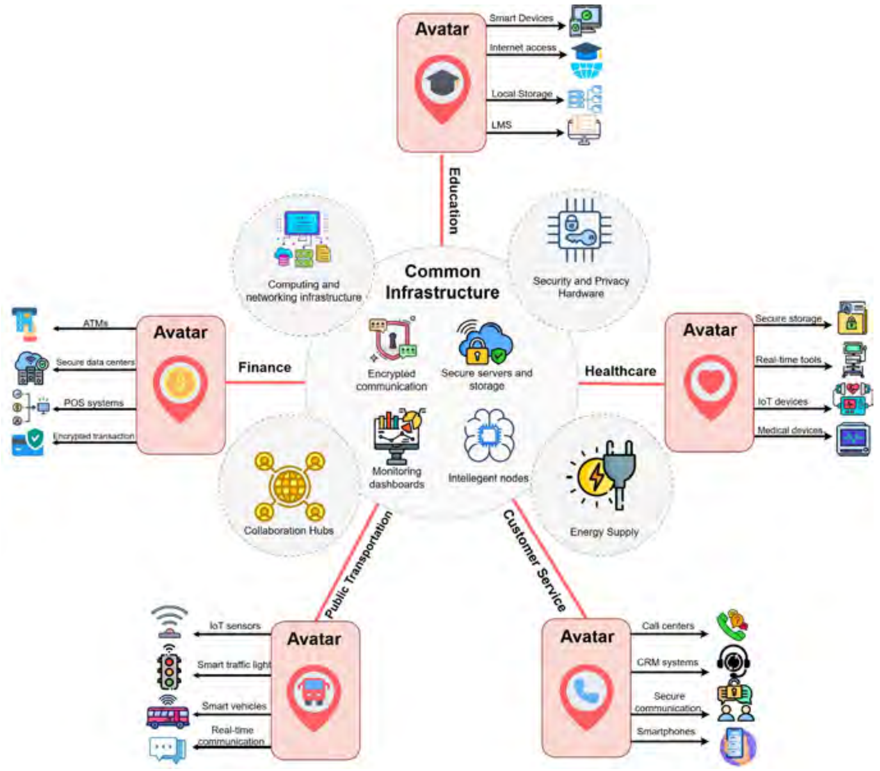

Figure 5. Real-time infrastructure of avatar-based ArSL interpreter in smart cities.

The execution layer of FL infrastructure supports a broad range of computing devices based on unique use cases, including high-performance GPUs for training sophisticated diagnostic models, ruggedized CPUs for dynamic situations, and lightweight edge devices for smaller models, as shown in Figure 5. These devices require dependable power supply, with backup systems such as UPS or generators assuring continuous operation. Efficient systems keep servers running effectively, while ruggedized hardware enables operations in tough situations such as distant educational settings or transportation systems.

Centralized coordination is critical to achieving interoperability, scalability, and compliance within FL systems. A central hub implements established protocols for model integration, providing seamless collaboration among edge nodes and sectors. Regulatory compliance is crucial, including frameworks such as GDPR for financial services and HL7 standards for healthcare. Dashboards provide real-time monitoring of system performance, node involvement, and scalability, enabling more effective administration.

The adaptability of FL infrastructure is proven in a variety of domains. In healthcare, FL allows for collaborative training of diagnostic models across institutions while protecting sensitive patient information. FL enhances public transportation by allowing for real-time optimization of traffic patterns and route scheduling based on vehicle data. The education industry uses FL to construct personalized learning models based on dispersed datasets from numerous universities. FL improves customer experience by creating adaptable models that include feedback from remote contact centers. In finance, FL helps to identify fraud by allowing institutions to collaborate on transaction data, boosting accuracy while retaining secrecy. The FL-based avatar illustrates the power of decentralized, privacy-preserving machine learning by addressing sector-specific concerns, and fostering industry-wide innovation while assuring compliance, security, and efficiency.

6. Experimental Results

6.1. Simulation Setup

In this paper, VGG19 and VGG16 (Simonyan, 2014) deep learning models are used as backbone for the federated deep learning framework. Several experiments are conducted to select the best hyperparameters for this model. The performance is evaluated on ArASL2018 dataset (Latif et al., 2019) in terms of average training time, accuracy, precision, recall, and f1-score. Each experiment uses 64 data samples, with five clients (representing 5 avatars) trained over ten epochs. The federated averaging method aggregates gradients on the server side, while categorical cross entropy is used as a loss function. Softmax is used as an activation function, and stochastic gradient descent is used as a primary optimizer with a learning rate of 0.01.

6.2. Performance on ArSL Recognition

Table 2 summarizes the performance results of all FL-based models. This evaluation procedure provides a detailed understanding of the model's performance across various avatar's classification characteristics, ensuring its ability to handle various scenarios using several data splits. However, due to the imbalanced nature of the Arabic sign language dataset model's performance is assessed using accuracy and macro-averaging metrics. In imbalanced circumstances, macro-averaging is very useful since it treats all classes equally without being affected by the majority class. The FL-VGG19 has a high testing performance, achieving an accuracy of 98.8%, a precision of 98.79%, a recall of 98.78%, and an F1-score of 98.78%.

Model	Val. Acc	Test Acc.	Precision	Recall	F1-Score	Training time per client (sec.)	Training time per round (min.)
VGG16	97.30	98.70	98.72	98.71	98.71	60	5
VGG19	97.10	98.80	98.79	98.78	98.78	65	5.4

Table 2. Performance of VGG16 and VGG19 on avatar simulation dataset.

However, FL-VGG16 and FL-VGG19 show comparable performance across all metrics. FL-VGG16 achieves slightly higher validation accuracy, with a marginal difference of 0.2%, underscoring the minor discrepancies between the performances of the two models. VGG16 takes 60 seconds per avatar for local data training, while VGG19 takes 65 seconds. The additional layers in VGG19 slightly increase its computational requirements. On the other hand, VGG16 requires 5 minutes per training round, while VGG19 takes 5.4 minutes, reflecting the added computational complexity of VGG19. Overall, VGG19 offers slightly better performance metrics but at the cost of increased training time. The differences, however, are minimal, suggesting that either model could be suitable depending on the specific requirements of the application.]

7. Conclusion

This paper presents a foundational framework for creating an AI-powered virtual interpreter that can generate and interpret ArSL using a federated learning approach. This innovative FL-based avatar demonstrates realistic hand movements and authentic facial expressions and prioritizes privacy and data security by leveraging federated deep learning paradigm. The virtual interpreter can be effectively deployed in a smart city environment, enabling smart city technologies to be more inclusive and accessible. This proposed framework lays a groundwork for further enhancing the integration of sign language interpretation into various applications, ultimately fostering improved communication and interaction for the deaf and hard-of-hearing population in urban settings.

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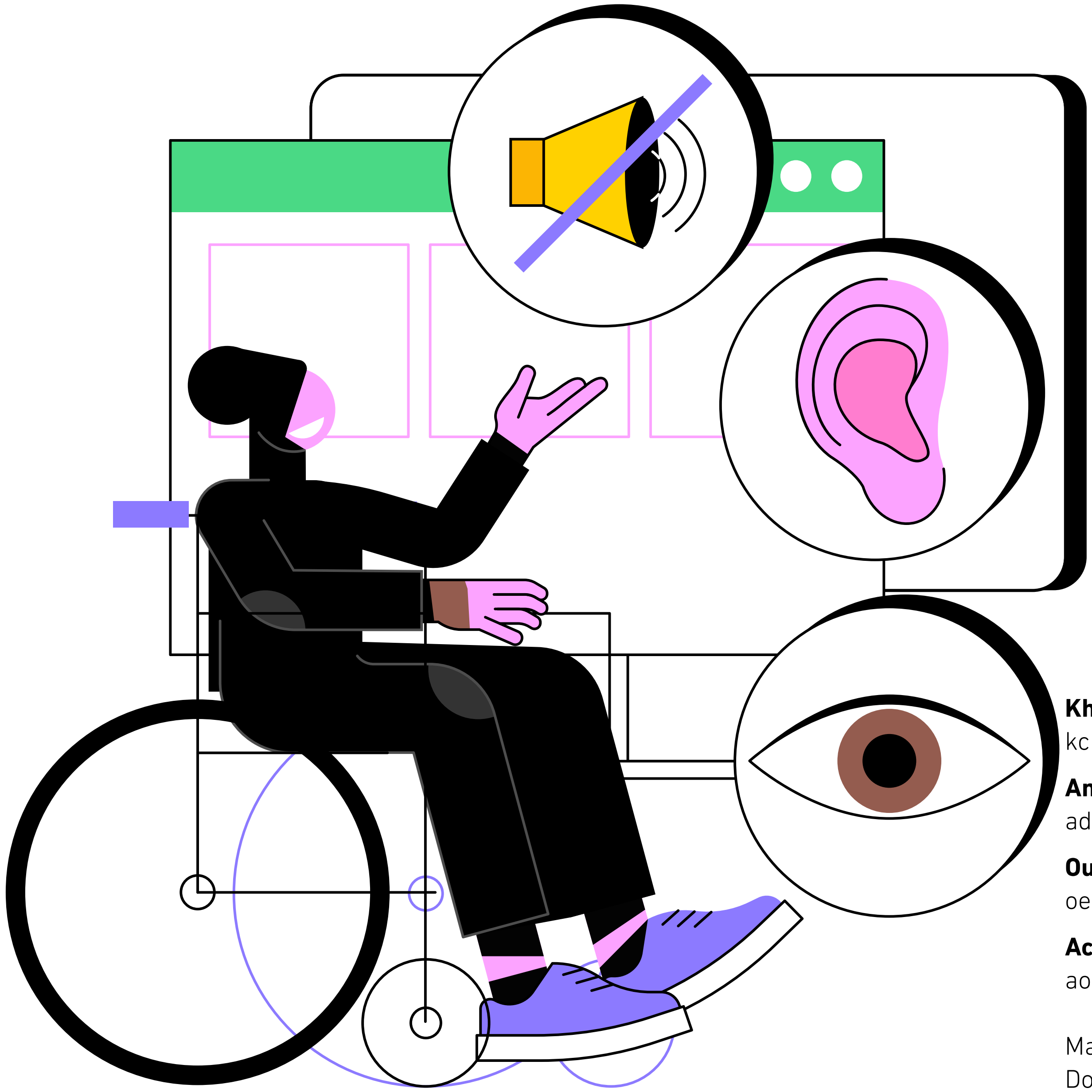
From Research to Impact Key Insights from Mada Edge



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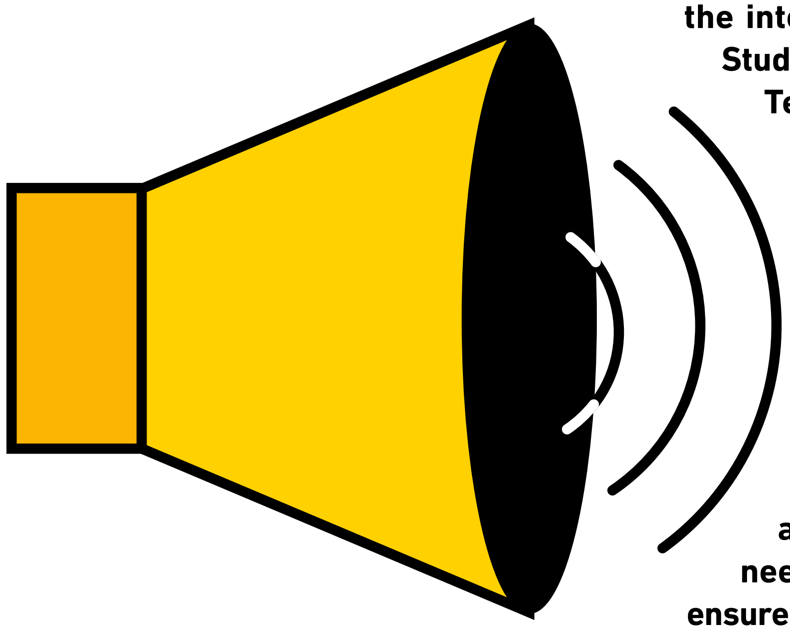
Abstract - Mada Edge stands at the forefront of digital accessibility and assistive technologies, leading pioneering research and innovation to address accessibility barriers for people with disabilities. This paper provides a comprehensive analysis of the center's interdisciplinary studies, significant publications, and large-scale projects. Key initiatives such as the Jumla Sign Language Project and the BuHamad virtual interpreter exemplify transformative advancements in promoting inclusivity across events, governmental initiatives, and educational platforms. The breadth of publications spans multiple domains and types, reflecting Mada Edge's holistic approach to digital accessibility research.



Keywords - sign language, assistive technologies, accessibility, interdisciplinary

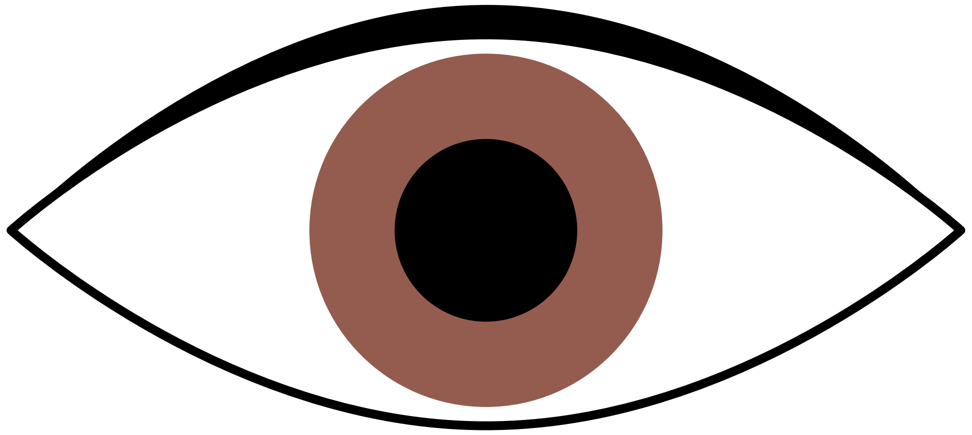
1. Introduction

One of the major global challenges is the persistent digital divide faced by people with disabilities, limiting their access to essential services, education, and public participation. Despite technological advancements, accessibility barriers continue to exclude significant portions of the population. In the United States, only 63.8% of people with disabilities use the internet compared to 83.4% of those without disabilities [1]. This digital exclusion is further exacerbated by the high costs of home internet, unemployment rates, and accessibility issues with websites and digital content. In the Arab world, the digital divide is particularly pronounced. Data from Arab Barometer surveys indicate that internet usage rates differ markedly along demographic lines, with disadvantaged segments of society, including persons with disabilities, being less likely to use the internet. The Arab Web Accessibility Study, conducted by Mada, the Assistive Technology Center Qatar, provides compelling evidence of the lack of digital accessibility in the Arab world. This comprehensive study evaluated over 4000 websites across 22 Arab countries, covering sectors such as government, education, healthcare, and commerce. The findings reveal significant gaps in web accessibility standards across the region, highlighting the need for substantial improvements to ensure digital inclusivity for individuals with disabilities [2]. Furthermore, a scoping review of assistive technology (AT) interventions for individuals with autism spectrum disorder (ASD) in Arab countries identified

several barriers to digital accessibility [3]. These include caregiver uncertainty about the use of AT and a lack of awareness among professionals and the general Arab community regarding assistive technologies. The review emphasizes the scarcity of data on the prevalence and effectiveness of AT use for individuals with ASD in Arab countries, indicating a need for more rigorous studies across diverse demographic groups and national regions [3].

Mada Edge addresses this pressing issue by advancing digital accessibility and assistive technologies through rigorous research and innovation. The center focuses on bridging gaps by fostering interdisciplinary collaboration, generating impactful knowledge, and developing tailored solutions for diverse disability groups. In Qatar, Mada Center has been at the forefront of enhancing digital accessibility. The center has contributed to the development of the National e-Accessibility Policy, a pioneering document in the MENA region that addresses accessibility to websites, mobile apps, telecommunications services, and public access electronic kiosks [4]. Mada has also influenced key policies in Qatar's digital sector, ensuring the implementation of digital accessibility standards in government services [5].

This paper highlights Mada Edge's key contributions, showcasing how its research has translated into tangible societal impact and fostered greater inclusivity in various sectors. The integration of digital accessibility within technological advancements is paramount in empowering individuals with disabilities, fostering equitable access to communication, technology, and public services. Mada Edge leads this mission through rigorous research and innovation in assistive technologies. The center focuses on addressing accessibility gaps by fostering interdisciplinary research, generating knowledge, and developing assistive solutions. Collaborations with international organizations and governmental bodies ensure that innovations align with the diverse needs of people with disabilities. This paper outlines major initiatives and highlights contributions from Mada Edge's research activities between the period 2022 - 2024, underpinned by comprehensive publications across various domains.



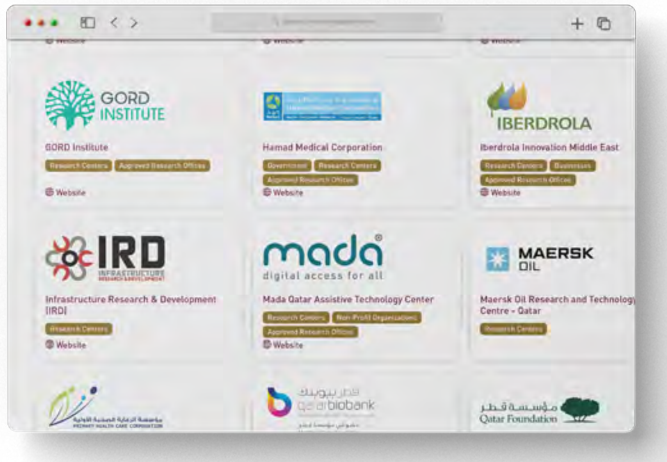
2. Research Center Accreditation and Achievements

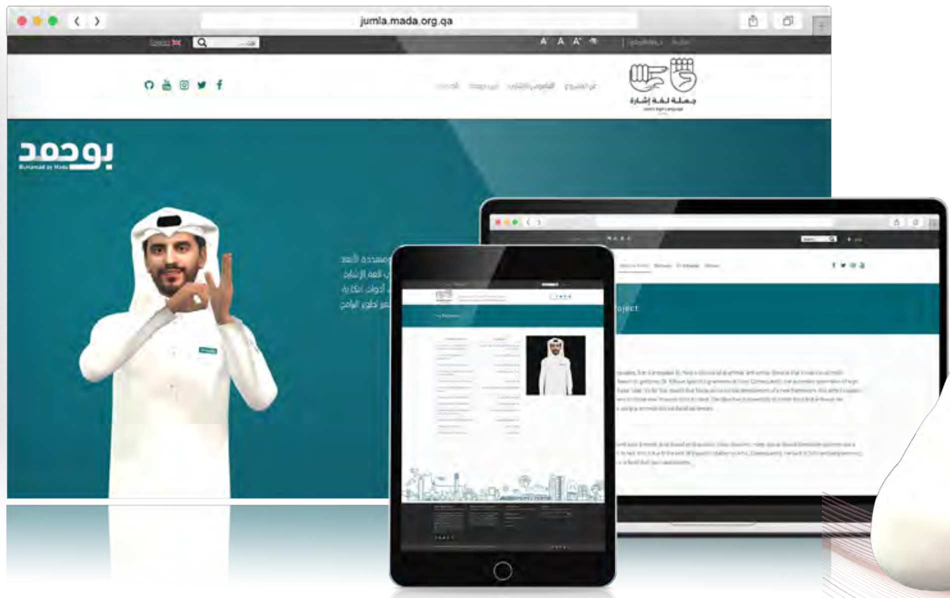
The accreditation of Mada Center by QRDI as an official research institution signifies a significant milestone [6], reinforcing its commitment to producing high-quality research outputs. This recognition underscores the center's contributions to academic literature, technological innovation, and policy development in the realm of digital inclusivity. Notable achievements include the publication of numerous peer-reviewed articles, book chapters, and conference papers addressing assistive technologies and inclusive design. Mada Edge's publications span 29 outputs, including 9 journal articles, 7 conference papers, 7 literature reviews, and 2 datasets during the period 2022-2024.

3. Major Projects and Initiatives

3.1. Jumla Sign Language Project

The Jumla Sign Language Project is a milestone in enhancing accessibility for the hearing-impaired community. The initiative developed the first extensive Qatari Sign Language dataset to advance continuous sign language processing [7]. Key achievements included collection of over 10,000 motion capture records over two years, video recordings of 900 sentences signed by 50+ hearing-impaired individuals and two sign language interpreters, and multi-angle, true-depth video captures for enhanced accuracy and flexibility. This project bridges significant communication gaps for the hearing-impaired community.





3.2. BuHamad Trademar

BuHamad, Qatar's first 3D virtual sign language interpreter, highlights Mada Edge's innovation [8]. Achieving 98% sign cloning accuracy, BuHamad is trusted and embraced by the deaf community. Key deployments include on the Ministry of Social Development and Family website [9], at the AFC Asian Cup Qatar 2023 [10], FIFA 2022 [11], and in Qatar Airways safety videos [12]. The BuHamad interpreter enhances accessibility for the deaf community by providing real-time interpretation services. Acceptance by the community and successful public deployment underscore the significance of this initiative in bridging communication gaps and promoting inclusivity.

3.3. Majlis and Nafath Periodicals

Mada Edge organized Nafath Majlis, a quarterly event aligned with the Nafath periodical, to discuss trends in digital accessibility and assistive technology [13]. Topics covered include Interdisciplinary Approaches in Assistive Technologies, Next-Generation User Interfaces, Advances in Sign Language Processing, Accessibility Standards and Innovations. These sessions facilitated knowledge exchange and collaboration within the field.

NAFATH
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3.4. Arab Web Accessibility Study

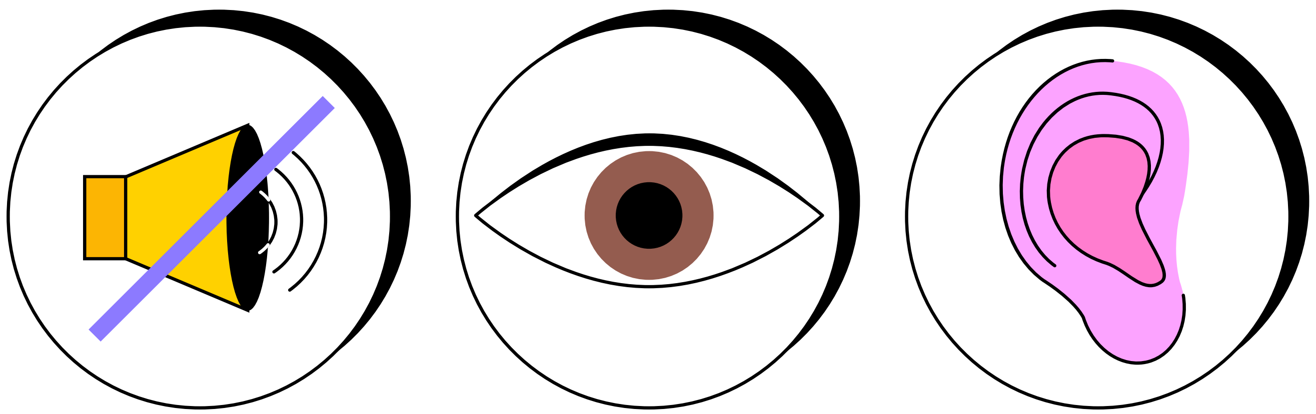
The Arab Web Accessibility Study evaluated over 4000 websites across Arab countries to assess their compliance with international accessibility standards [2]. This large-scale study provided valuable insights into sector-wise accessibility gaps, emphasizing the need for enhanced digital inclusivity in the Arab region. Key findings highlight disparities in accessibility across government, educational, and commercial sectors, prompting targeted recommendations for improving web accessibility.

3.5. International Consortium and Collaboration

Mada Edge actively collaborated with international partners through consortiums and joint research projects. These partnerships facilitated knowledge exchange, fostering innovation in assistive technologies. Mada Edge's involvement in global conferences and workshops amplified awareness of digital accessibility challenges, contributing to the development of inclusive policies and solutions on a global scale.

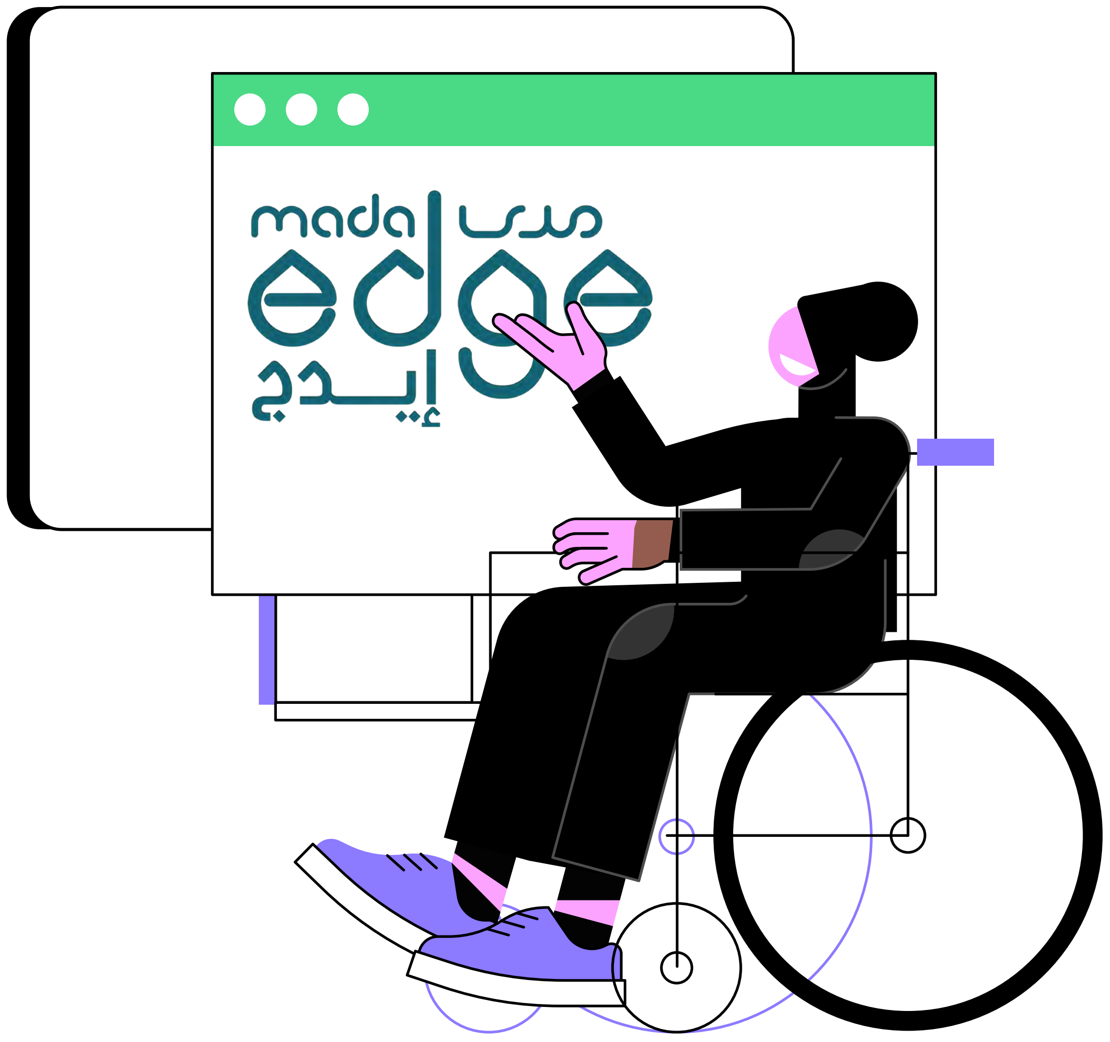
3.6. Publication Domains Focus

Mada Edge's research initiatives spanned multiple domains and addressed various types of disabilities. A significant portion of Mada Edge's publications targeted assistive technologies, with 13 papers dedicated to this domain, reflecting the center's core mission of enhancing accessibility tools and resources. Special education and autism research formed another vital area, comprising 8 papers aimed at supporting individuals with autism spectrum disorder [14,15]. Digital accessibility initiatives included 6 papers, highlighting efforts to ensure inclusive digital environments [5,16,17]. Additionally, Mada Edge explored artificial intelligence in education [18,19], elderly care technology, and cultural accessibility, each with 2 papers. The center also addressed various types of disabilities, with papers focusing on hearing impairments [20], autism spectrum disorder [21], general disabilities, and to elderly and cognitive impairments [22,23]. These publications exemplified Mada Edge's commitment to broadening the scope of accessibility solutions across multiple sectors and communities.



4. Conclusion and Future Directions

Mada Edge has consistently demonstrated its leadership in advancing digital accessibility and assistive technologies through rigorous research, impactful publications, and groundbreaking projects. By addressing the needs of diverse disability groups and fostering interdisciplinary collaboration, Mada Edge has set a strong foundation for inclusive innovation. The success of initiatives like the Jumla Sign Language Project and the BuHamad virtual interpreter highlights the tangible benefits of applied research in bridging accessibility gaps. Mada Edge aims to expand its influence lutions and strengthening international collaborations. Future efforts will focus on addressing emerging challenges in accessibility, ensuring equitable access to digital resources for all communities. Through continued innovation and knowledge-sharing, Mada Edge aspires to shape a more inclusive and technologically advanced society, empowering individuals with disabilities to thrive in an increasingly digital world.



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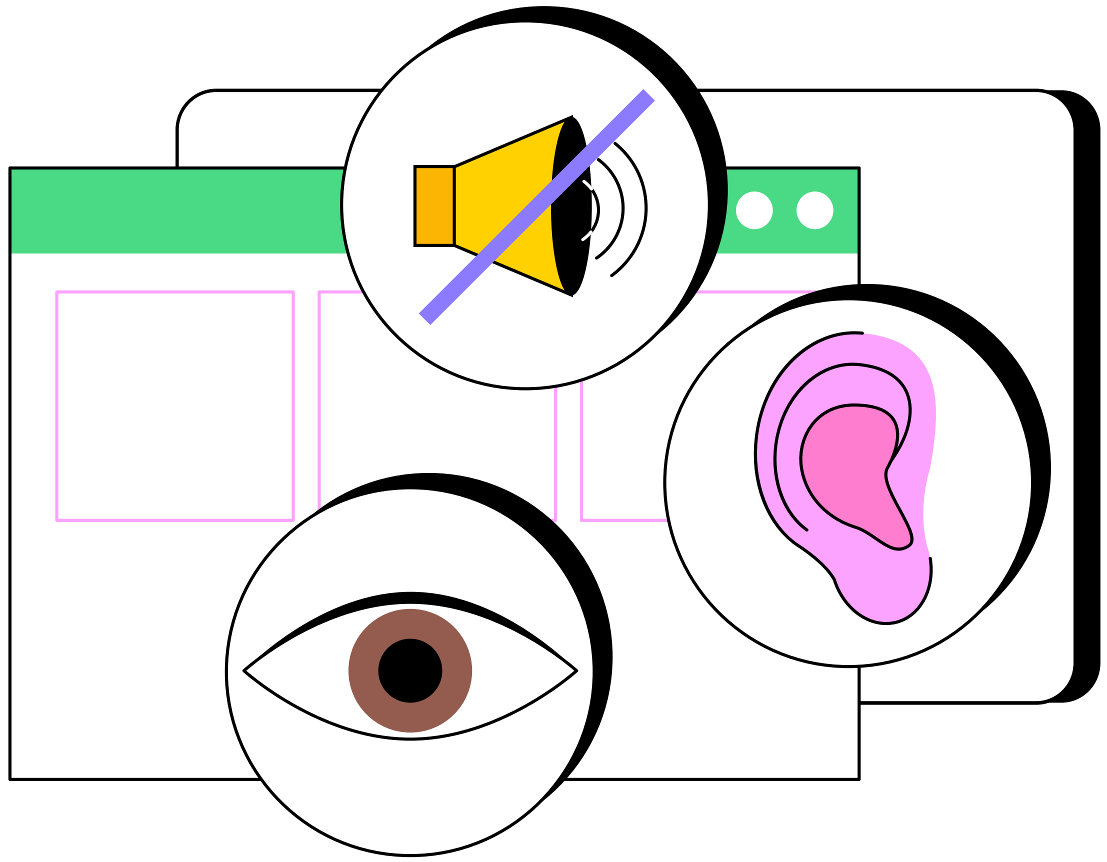

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