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Accessibility and Activity-Centered Design for ICT Users: ACCESIBILITIC Ontology

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ABSTRACT Information and communication technologies (ICTs) are involved in daily human activities. Accessibility guarantees that individuals with different abilities can interact with ICTs. User profile models are an explicit representation of the characteristics of an individual and are used to reason about what users need. They are implemented through ontologies. After identifying common and different aspects among important ontologies in the domain of accessibility and e-inclusion, we designed and implemented the ACCESIBILITIC ontology applying the NeOn methodology, specifically by reusing and reengineering these ontologies. The strengths of our model include the user's ability to develop a high variety of activities despite his/her disabilities, support for inference processes, and providing answers to several competency questions. ACCESIBILITIC allows the representation of suitable technical support based on the user's capabilities when interacting with ICTs. To this end, we use an activity-centered design (ACD), which allows us to identify daily activities and to match these activities with a suitable technology to perform them.

INDEX TERMS Human-computer interaction, information technology, modeling, user interfaces.

I. INTRODUCTION

The World Health Organization (WHO) [1], considers a disability as part of the human condition, because every person will be temporarily or permanently impaired at some point in life, especially at old age because of increasing difficulties in body functions. Disability and impairments are complex phenomena related to the interaction between the characteristics of our human nature and the characteristics of the society in which we live.

Information and Communication Technologies (ICTs) are used to facilitate the performance of daily tasks and to support communication. In the case of persons with disabilities, according to United Nations (UN) [2] their access to ICT should be guaranteed as a human right. In this sense, Accessibility is considered a key factor to encourage digital inclusion in society. Accessibility is a global requirement for access to information by individuals with different abilities, requirements and preferences, in a variety of contexts of use [3].

It is important to understand how people interact with ICT and how this interaction can be improved in order to successfully introduce new technologies, taking into account people's needs and expectations. In particular, Activity-Centered Design (ACD) offers an activity-centric view of human-computer interaction and encourages designers to concentrate on developing high-level human activities [4]–[8]. ACD requires a deep knowledge of people, context, technology, tools, and the motivations for the activities [8].

Customization, adaptation and construction of accessible ICTs allow us to solve the digital divide of users with special needs, improving their user experience and the quality of their interactions. To make it effective, it is necessary to know the possibilities of support that ICTs offer.

Our proposal is to create a model of accessibility for ICT users, called ACCESIBILITIC, in order to: model the main characteristics of ICTs users, know if a user is able to interact with ICTs, suggest suitable support assistance to facilitate overall accessibility, and support ACD by identifying day-to-day activities a user is able to perform according to his/her capabilities. In the future, the model can be used by a recommender system to suggest software adaptations, customizations, or technical support to software developers and designers.

There are previous projects in which ontologies have been used to model users in the accessibility and e-inclusion domain such as User Impairments, ADOLENA, ASK-IT, AEGIS/ACCESSIBLE, Affinto and Egonto. Those ontologies are the basis for our proposed model, which is more complete than the previous models and provides a better fit of ICT support characteristics.

The remainder of this paper is organized as follows: Section II describes related work, Section III focuses in Activity-Centered Design, Section IV shows how the new ontology was developed, Section V describes the ontology reasoning of ACCESIBILITIC, and Section VI summarizes conclusions and future work.

II. RELATED WORK

Ontologies are modeling tools that allow performing designs, establishing relationships, and formulating axioms to infer and deduce information. An ontology specifies vocabulary related to a certain domain. The vocabulary defines entities, classes, properties, predicates and functions, in addition to the relationships between these components [9], [10]. Ontological engineering allows the representation of knowledge, the identification of a context, and the verification of information dependence more easily than other data modeling tools [11].

Ontologies are widely used in different disciplines. The use of ontologies in the health domain is an active field of research because systems based on ontologies help improve the management of complex health systems [12]. In this domain, the creation of user profiles based on ontological models allows a homogeneous representation of the user in terms of their characteristics, such as their needs and preferences. In addition, when sharing and reusing a profile between different systems, the use of ontologies is an advantage because it provides the opportunity to reason along with the rest of the components of these systems [13]. In the health domain, ontologies are used in a nutritional semantic recommender system for the elderly [14], and the storage of health records for interoperability in medical systems [15].

There are also some ontologies created specifically to model user accessibility and assistive technologies as described below.

The International Classification of Functioning, Disability and Health, known more commonly as ICF, was created by [16] as a product of the revision of the International Classification of Impairments, Disabilities, and Handicaps (ICIDH) of 1980. Its main objective is to provide a unified and standardized language, and a conceptual framework to describe health and health-related states. It was approved for international use in May 2001 and has its own ontology. Besides, the ICF classification has been used to model the interaction between humans and devices within the context of the information society [17].

Karim and Tjoa [18] propose two ontologies, User impairments and User Interfaces, in the domain of a hospital information system to demonstrate how through the technology of the semantic web it was possible to connect user interface features according to the users' disabilities and capacities.

The Abilities and Disabilities OntoLogy for ENhancing Accessibility (ADOLENA) [19] is an ontology of skills and disabilities to improve accessibility. It was designed to demonstrate the proof-of-concept of Ontology Based Data Access (OBDA) with a real database, using the database of the web National Accessibility Portal of South Africa. It is based on the "International Classification of Functioning, Disability and Health" (ICIDH-2) [20] which is an earlier version of the ICF. The ICIDH-2 classification provides a standard and unified language for the description of health and health-related states. It focuses on the user model of the ICF and the functionality of the assistive devices.

The project of "Ambient Intelligence System of Agents for Knowledge-based and Integrated Services for Mobility Impaired users" (ASK-IT) [21] has its own ontology which describes the needs of users with reduced mobility, and defines services to support planning trips, moving from one city to another or executing home control activities during a trip. It focuses on the modelling of reduced mobility users, agents and services.

The project of "Accessibility Assessment Simulation Environment for New Applications Design and Development" (ACCESSIBLE) [22], aims to develop an environment to gather and merge different methodological tools. Its ontology has three dimensions: Generic Ontology, Domain Specific Ontology and Ontology Rules. It focuses on the ICF user model, assistive technologies (assistive devices), web accessibility initiative guidelines (WAI-ARIA) and most accessible web applications for people with disabilities.

The project of "Open Accessibility Everywhere: Groundwork, Infrastructure, Standards" (AEGIS) [23] is based on User Centered Design (UCD). The AEGIS ontology is the result of this project. It provides support for the formal and unambiguous definition of accessibility domains, and for possible semantic interactions between its concepts [24], [25].

The AEGIS ontology covers the following aspects [26]: 1) Personal aspects: characteristics of users with disabilities, functional limitations and disabilities. 2) Technical aspects: technical characteristics of the I/O devices, general and functional characteristics of web, desktop and mobile applications and other assistive technologies that must be taken into account when describing users with disabilities and developing software applications. 3) Natural aspects: user actions and logical interactions while using the applications.

The ontologies of the last two projects described above were integrated into a single ontology called AEGIS/ACCESSIBLE. A small part of the ACCESSIBLE ontology was imported for the purpose of covering the personal aspects of AEGIS [27].

The ontology Affinto [28], [29] is used to represent a context model of affective person-system interactions. It is extensible because it allows the introduction of new information on interactions. In addition, it has a global architecture for the development of affective resources that offer users more intelligence and natural interfaces. This approach is centered on the user model for physical, cognitive and emotional capacities; assistive technologies (software devices); and context-based modeling.

The Egonto ontology [30] is used to store, update and maintain models of user skills, characteristics of the access devices and the interface adaptations. It focuses on the user model for physical, cognitive, sensory and emotional capacities; as well as assistive technologies (hardware and software), and an adaptation model to offer individual users customized support.

As a sample of the application of user profiles with disabilities in a specific domain like e-business, and considering some of the ontologies described above, we proposed and ontological approach in [31]. In this research, ontologies such as: ACCESSIBLE, ICF and BMO (Business Model Ontology) were reused and reengineered.

In summary, all the ontologies and resources analyzed model users with disabilities, but only four of them (User Impairment, ADOLENA, Affinto and Egonto) also characterize the skills and capabilities of the users. It is important to know them to provide alternatives of interaction and adapted interfaces based on them. The User Interface, Affinto and Egonto ontologies model some kind of interface adaptation related to the users' capabilities but the first one does not characterize aspects related to the interaction. ADOLENA, Affinto, Egonto and AEGIS/ACCESSIBLE ontologies are the only ones that also categorize assistive devices, but none of them consider software tools to improve or provide accessibility. Their instantiations regarding this concept are not updated with current technologies. Finally, ASK-IT is the only ontology that could support ACD because it models user activities, although it instantiates only some activities for people with mobility impairments because it only models this kind of user.

III. ACTIVITY-CENTERED DESIGN (ACD)

Our use case needs to identify users' needs and abilities to properly recommend the technology (software adaptation and hardware). Human Centered Design (HCD) retrieves user information, but does not identify the activities. Therefore, we also need to use Activity Centered Design (ACD), which covers the activities. Once we know the activities we can infer the technology needed to perform these activities.

Activity is considered one of the most fundamental concepts in HCI research and also it is a challenge in interaction design. Activity is a set of mental or physical actions carried out by people [32].

Human activities suggest a range of possible actions and the circumstances (and limitations) under which users can function [8]

Li and Landay [7] stated that ACD uses long-term and high-level activities for the analysis and design of a hierarchy of simpler tasks (actions and operations into actions), which have been the center of attention of traditional approaches. Particularly, Activity Theory (AT) uses an activity hierarchy to describe human activities with the following three elements: activities, actions, and operations [7].

In a similar manner Norman considers that the highest level are activities, which are composed of tasks, which themselves are composed of actions, and actions are made up of operations. So, ACD requires a deep understanding of people, of the technology, of the tools, and of the reasons for the activities [8].

IV. ACCESIBILITIC: PROPOSED ONTOLOGY TO MODEL ACCESSIBILITY FOR ICTS USERS

The main objectives of our new ontology, called ACCESIBILITIC, are: (1) Model the functional diversity of users, focusing on users' capabilities, more than on users' limitations; (2) Characterize assistive devices and software tools used to support accessibility; (3) Model the user's interaction taking into account capabilities, disabilities, devices and software tools; and (4) Characterize the user's participation in daily life activities using ITCs taking into account ACD.

None of the ontologies reviewed fulfill individually all of these objectives.

The ACCESIBILITIC ontology has to model the main characteristics of ICTs users, including their capabilities, disabilities, the state of their physiological and psychological functions, and the technology characteristics related to accessibility. This allows us to determine whether a user is able to interact with ICTs and also to provide suitable support assistance (hardware, software or adaptive strategies) to facilitate overall accessibility.

Regarding the identification of daily life activities that users are able to perform, their capabilities (cognitive, motor, sensorial and speech) have to be considered. We propose to identify activities as the basis for ACD. Consequently ACCESIBILITIC can support ACD if it is integrated with an ontology module of a specific domain where user tasks, actions and operations are categorized.

Part of some knowledge resources and ontologies will be reused and reengineered, such as: ICF, User Impairments, ADOLENA, ASK-IT, AEGIS/ACCESSIBLE, Affinto and Egonto.

ACCESIBILITIC will be integrated with an ontology module that allows us to model the Customer Relationships Management (CRM) domain and to identify how users/customers with disabilities can be accompanied when they interact with ICTs during their buying cycle. In a previous work [31] an ontological approach were proposed to identify weaknesses in the Buying Cycle of Customers [38] with disabilities, and to help to enhance the user interface of e-business systems, specifically customer relationship aspects, during the development process.

In this section, we outline our design requirements, and the methodology to create the new ontology, specifically the process of reengineering the ontology.

A. REQUIREMENTS TO BE MODELED IN THE ONTOLOGY

The main concepts to be modeled in the ACCESIBILITIC ontology are: Users, Impairments, Disabilities and Capabilities of the users, Body Functions, Activities and Participations, and Support Assistant (technical support) that could be offered considering the disabilities and capabilities of the users. These concepts are described as follows:

1) USER

Describes the attributes of the person interacting with ICT, it is based on hypothetical archetypes of users considering their disabilities in AEGIS [23] and capabilities were incorporated according to users' descriptions and their technology usage.

2) IMPAIRMENT

Illustrates problems related to the body function or structure as a significant deviation or loss [33]. The five categories of dysfunctions proposed by AEGIS/ACCESSIBLE are: Vision, Upper Limb, Cognitive, Hearing, and Communication.

3) DISABILITY

Represents a subset of impairments that can be temporary or permanent, partial or total. Each impairment category is associated with one or more disabilities.

4) CAPABILITY

Describes the abilities of the user to interact with ICTs, including cognitive, sensory, motor and speech.

5) BODY FUNCTION

Characterizes physiological and psychological functions, which influence specific capabilities. They are classified as mental, sensory, voice and speech, and neuromusculoskeletal [33].

6) ACTIVITY PARTICIPATION

Describes specific actions that the users can carry out to interact with ICTs and, consequently, that help them to perform day-to-day life activities. Users with specific capabilities can carry out activities and participate in society [33].

7) SUPPORT ASSISTANCE

Also known as technical support, it refers to a variety of forms of assistance provided by devices or software (standards or adapted), as well as software adaptive strategies, to help users with special needs to interact with ICTs. Each support assistant is recommended according to specific disabilities and/or capabilities.

Finally, the profile of a user is given by the instantiation of these concepts and their relationships.

B. METHODOLOGY: PROCESS OF REENGINEERING THE ONTOLOGY

The methodology followed to create the proposed ontology is NeOn [34], specifically scenario 4, in which a new ontology is created reusing others and applying reengineering.

The NeON methodology includes three phases: ontology reverse engineering, ontology restructuring, and ontology forward engineering. Their application is described in subsequent subsections.

1) ONTOLOGY REVERSE ENGINEERING

The main objective of the reverse engineering phase is to define the conceptual model of an ontology from its source code [35].

The knowledge resources and ontologies reviewed in the previous section will be analyzed here because they model the main characteristics of users in health and interaction domains. In addition, some of them characterize ICT accessibility aspects, according to our requirements. The use of reverse engineering is necessary because the majority of these resources and ontologies do not provide detailed information about their structure, components and properties. To implement the new ontology, the W3C Web Ontology Language (OWL) is used.

The first resource to be analyzed is the ICF classification [33], which focuses on body functions that can be affected depending on the person's disabilities. The hierarchical structure of this concept is shown in Table 1.

TABLE 1. Hierarchical structure of body function concept in ICF.

Mental function	
	-Global mental functions
	-Specific Mental Functions
Sensory function and pain	
	-Hearing and vestibular functions
	-Seeing and related functions
Voice and speech function	
	-Fluency and rhythm of speech functions
	-Voice functions
	-Articulation functions
Neuromusculoskeletal and movement-related function	
	-Mobility of bone function
	-Stability of joint function
	-Control of voluntary movement function
	-Gait pattern function
	-Movement function, other specified and unspecified
	-Neuromusculoskeletal and movement-related function, other specified
	-Sensations related to muscles and movement function

ICF has been considered for modelling human-computer interactions within the context of the Information Society [17]. This study resulted in a classification of human skills. Table 2 shows the hierarchy of some of these abilities. This classification can be used to model user capabilities in the use of ICTs.

Regarding the ontology of User Impairments, it includes four classes: Capability, Perception, Measure and Impairment. Each one with subclasses to model different kinds of

TABLE 2. Some of the user abilities for interaction classified in ICF.

K0 Keys/buttons control
K00 Functional
K000 To press a single key/button
K001 To press multiple keys/buttons
K002 To control a key/button pressing over time
K01 Format
K010 Reduced
K011 Extended
K012 Virtual (on screen) key/button
K013 Projected or holographic key/button
K1 Write capable
K10 Using a keyboard
K100 QWERTY
K101 Keypad
K102 Chord
K11 By hand on Screen
K12 Articulating voice to input text
K2 Pointing
K3 Clicking
K4 Making Gestures

impairment according to each affected part of the body (e.g. visual, motor and cognitive impairments).

It is interesting to evaluate the scope of instances of the class Capability, such as: Memory, Speech, Reading, Writing, Attention, Hearing, Vision, Touch, Taste and Smell.

The following ontology to be considered is ADOLENA, which includes the following classes: Ability, Device and Disability. It proposes that each capability is influenced by any disability and each disability is supported by a device. Table 3 shows the hierarchy of the class Ability.

TABLE 3. Hierarchical structure of the class ability in ADOLENA.

PhysicalAbility
- MovementAbility
- LimbMobility
- Reach
SensoryAbility
- HearingAbility
- Hear
- Hear_partially
- SightAbility
- See
- See_partially
- TactileAbility
SpeechAbility

The ASK-IT ontology was analysed, it is more focused on characterizing users with reduced mobility. It has a class called Limitation, whose subclasses are specialized in several kinds of impairment:

–CognitiveLimitation,
–CommunicationLimitation,
–HearingLimitation,
–LowerLimbLimitation,
–PsychologicalLimitation,
–Upper Body Limitation,
–UpperLimbLimitation,
–VisionLimitation, and
–Walking Limitation.

Each type of limitation affects one or more body functions in different degrees. For example, VisionLimitation is divided into:

–LightVisionLimitation,
–NightAndColorVisionLimitation,
–ReducedVisionLimitation, and
–SevereVisionLimitation.

The Affinto ontology considers concepts relative to sensory and perceptual processes that take part in the communication capability of the user with the system. Focusing on the Personal_property subclass, we found the CognitiveP_properties subclass subclassified into the following subclasses: memory, perceptual_process (language_perception and speech_perception) and sensory_process (auditory, kinesthesic, oral and visual). These concepts will be used to increase the details related to communication capability to reinforce our proposed ontology.

The AEGIS/ACCESSIBLE ontology has the classes: User, Disability, FunctionalLimitation, IODevice, Application and Impairment. Most of these classes are linked together, except the Application classes. We have analyzed the characteristics of these classes in depth in previous work [36]. Although it is focused on disabilities and does not differentiate specific subclasses, some of its classes can be reused in our new ontology.

The Egonto ontology presents an interesting user model to complement our ontological model. It focuses on the user communicative abilities class and consists of the following subclasses: affective, cognitive, physical (mobility and speech) and sensory. Different ability degrees are shown by each subclass. For example, the sight subclass of sensory can have values 001 for high vision and 002 for low vision.

2) ONTOLOGY RESTRUCTURING

The objective of this phase is to create the conceptual model of the ACCESIBILITIC ontology. The analysis and synthesis of different resources and ontologies, and the determination of requirements in the previous phase, are the starting point to create the new ontology. Table 4 summarizes the result of this phase. It consists of the classes of the ACCESIBILITIC ontology, the source ontology and the source class or concept related (synonymous). The majority of the classes of the new ontology have been improved from their original classes, they are more specialized with a new hierarchy of subclasses. The main characteristics of our seven classes and their properties are described as follows:

a: USER

In order to know which Support Assistant to suggest to any user and to infer which activities and participation he/she is able to perform, class User is linked to classes Disability and Capability with the object properties "hasDisability" and "hasCapability", respectively. The data properties assertion of a user are the same as in the AEGIS/ACCESSIBLE ontology: hasName, hasDescription, Meet, hasMaritalStatus,

TABLE 4. Classes of ACCESSIBIITIC ontology and their origin.

ACCESSIBILITIC Classes	Source Ontology	Source Class or Concept
User	AEGIS/ACCESSIBLE	-User
Impairment	AEGIS/ACCESSIBLE	-Impairment
Disability	AEGIS/ACCESSIBLE	-Disability
BodyFunction	ICF AEGIS/ACCESSIBLE	-Body Functions -FunctionalLimitation
Capability	ICF User Impairments Affinto	-Classification of Skills -Capability -CognitiveP_properties: perceptual_process and sensorial_process -personal_property
	Egonto	-User_communicative_ abilities: affective, cognitive, physic and sensory
	ASK-IT	-Limitation
ActivityParticipation	ICF	-ActivityParticipation
SupportAssistance	AEGIS/ACCESSIBLE	-Device

hasJob, hasEducation, hasLocation, TechnologyUsage, and hasAge.

b: IMPAIRMENT

This class was taken from the AEGIS/ACCESSIBLE ontology, it has no data property assertion, and therefore we added some data property assertions as annotations such as ''hasDescription'' and ''hasName''. The old object property assertion was eliminated and now it is linked to the class Disability by the object property ''includes'' to associate specific disabilities to an impairment. Five main impartments are considered: Cognitive, Hearing, Communication, Vision, and UpperLimb.

c: DISABILITY

During the interaction of users with ICTs, their disabilities can be solved if they use the right support assistance such as an application, device or software adaptation, so we have related both classes. This is one of our main contributions to characterize in a positive way users with special needs, not only from the impairment or disease perspective. The object property ''needs'' links the class Disability to the class SupportAssistance. Other object properties are ''associatedWith'', which links the class Disability to the class BodyFunction to explain the cause of the disability, and ''belongsTo'' to classify the class Disability into a type of Impairment. In our proposed ontology we added these two data properties as annotations, they are ''hasDescription'' and ''hasName''. Also, we created Defined Classes (Equivalent Class) to group Disability instances according to each Impairment. Fig. 1 shows defined classes of class Disability.

FIGURE 1. Defined Classes of Class Disability.

d: BODYFUNCTION

The ICF classification was used to sub-classify different physiological and psychological functions of the user. Considering that every capability involves one or more specific body functions, there is an object property called ''relatedTo'' that links BodyFunction to Capability. Each BodyFunction ''is AffectedBy'' (object property) some Disability. As an advantage of the Disability subclasification, an association between specific body functions and disabilities can be defined. The data properties of BodyFunction are defined as annotations, they are ''hasName'', ''hasDescription'', and ''hasId''. The hierarchy of the class BodyFunction is shown in Fig. 2 (a).

e: CAPABILITY

It is the alternative combinations of functioning (beings and doings) that a person can achieve [37]. The main strength of our ontology is representing that users can develop a high variety of capabilities despite their disabilities. The Capability class in our ontology has been created taking into account different ontologies with the base of ICF. The classification of skills based on ICF is very essential because it allows the characterization of very specific skills to interact with ICTs. For example, differentiating between abilities to touch a tablet with a finger and abilities to touch it with another device. This classification helps us to expand in-depth the Motor Capability subcategories.

The User Impairment Ontology hierarchy allows us to recognize that it is necessary to create a relationship between Capability and Body function with the object property ''isDueTo'', because each capability is possibly due to specific body functions, the inverse relation is ''relatedTo''. The capabilities considered in this ontology, although with a general approach, give us new ideas about synonyms of capabilities. For example, Speech capability is named SpeechAbility in the ADOLENA ontology and Speech in the Egonto ontology, but it is a subcategory of the physical ability of the user's communicative ability. Therefore we created the class Speech Capability in our new ontology to express the positive side (ability) of communication impairment.

The Affinto ontology was also used because it provides a classification of personal_property, specifically cognitive properties, it consist of the process sensory and perceptual. In our new ontology we added SensorialCapability and PerceptualCapability to categorize them. Finally, the Egonto ontology allows the identification of affective capabilities of the user when interacting with other users and ICTs, so we

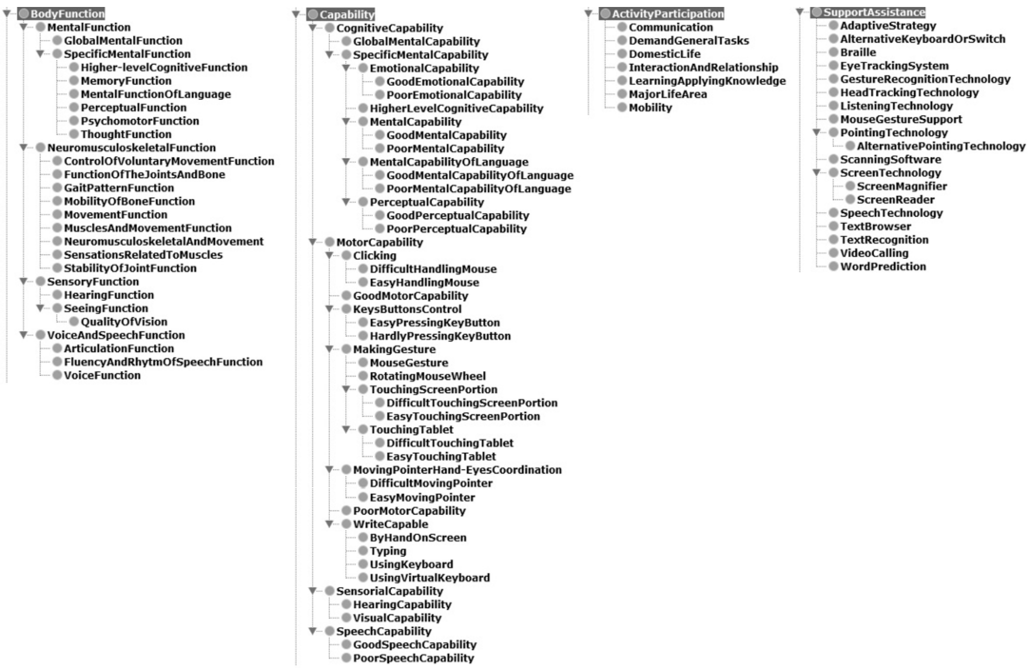

FIGURE 2. **Hierarchy of Classes: (a) BodyFunction, (b) Capability, (c) ActivityParticipation, and (d) SupportAssistance.**

added the subclass EmotionalCapability and completed the classification of CognitiveCapability.

With regard to the ADOLENA ontology, its Ability class is relevant because of its sub classification with degrees of ability. This idea is complemented with the ASK-IT ontology, specifically the complex hierarchy of the class Limitation. We are not focusing on the class meaning, we are looking for a more complete hierarchical structure of the class Capability to make it more specialized.

The ADOLENA ontology related the classes Ability and Device to highlight that specific Abilities are assisted by some Devices. This idea is extended in our ontology in the class SupportAssistance (discussed below). We use object property ''linksTo'' to relate Capability to Support Assistance, so with a more specialized class Capability we can suggest new ways of user interaction taking into account new technological support. The hierarchy of class Capability is shown in Fig. 2 (b).

ACCESIBILITIC includes a relationship through the object property ''contributesTo'' between the classes Capability and ActivityParticipation (discussed below). This relationship is an extension of the class Capability, because we propose the possibility to know which Activity and Participation users are able to perform according to their capability combination.

f: ACTIVITYPARTICIPATION

This class represents the union of the concepts Activity and Participation proposed by ICF [33]. In our ontology, the class ActivityParticipation represents activities that the user can carry out in daily life situations. Following ACD, this class has been designed to model the performance of people in the information society, and in our specific case interaction with ICT, which depends on their capabilities, instead of their disabilities. The class ActivityParticipation has the following data properties defined as annotations: ''hasDescription'', ''hasName'', and ''hasId''. Its hierarchy was structured considering to the ICF scheme [33] which is organized in chapters. The hierarchy of the Class ActivityParticipation is presented in Fig. 2 (c). Its subclasses are:

–LearningApplyingKnowledge,
–DemandGeneralTasks,
–Communication,
–Mobility,
–DomesticLife,
–InteractionAndRelationShip, and
–MajorLifeArea.

We have related the class ActivityParticipation to the class Capability with the object property ''dueTo''. Therefore, when the activities and participation of users are inferred, these will be according to the combination of user capabilities.

Considering the activity hierarchy used in the Activity Theory to describe human activities [7], we proposed that the ACCESIBILITIC ontology has, as the highest level of the activity hierarchy, the class ActivityParticipation. The following elements of the hierarchy (actions and operations) will be part of a specific domain ontology where ACD needs to be implemented, in this way the ACCESIBILITIC ontology has the basis for supporting ACD.

g: SUPPORTASSISTANCE

The AEGIS/ACCESSIBLE Ontology has a class named Device that imports instances of different kinds of hardware technologies to the users from 8 ontology modules (.owl) such as:

–Alternative_Keyboard_Or_Switches,
–Screen_Magnifiers,
–Braille,
–Screen_Reader,
–Listening_Devices,
–Speech_Devices,
–Scanning_Software, and
–Text_Browser.

The Egonto ontology also has the class Device related to the class User to represent devices used by users to help them to carry out activities. Our purpose was to rename and extend the class Device, we create the class SupportAssistance to categorize not only hardware devices, but also software applications and adaptive strategies that can be used by the user, taking into account their capabilities in order to perform activities. In this way, users with disabilities can perform an activity if they have capabilities or if they have support assistance.

The Class SupportAssistance has the following data properties defined as annotations, they are "hasDescription", "hasName", and "hasType". This last one is used to identify the following categories of SupportAssistance: Assistive Technology – Hardware, Assistive Technology – Software, Assistive Technology Hardware & Software, Standard Hardware, Standard Software, and Adaptive Strategy.

In our ontology we defined a relationship called "requires" between the classes SupportAssistance and Capability. Additionally, we created a relationship between the classes SupportAssistance and Disability, called "intendedFor". Taking into account the ontology modules of the class Device from AEGIS/ACCESSIBLE, we have updated the names of some of them and added new ones. The class SupportAssistance includes the following subclasess:

–PointingTechnology,
–ScreenTechnology,
–AdaptiveStrategy,
–EyeTrackingSystem,
–GestureRecognitionTechnology,
–HeadTrackingTechnology,
–ListeningTechnology,
–MouseGestureSupport,
–SpeechTechnology,
–TextRecognition, and
–WordPrediction.

If a new technology arises, it could be added as a new subclass or instance. Fig. 2 (d) shows the hierarchy of the class SupportAssistance.

3) ONTOLOGY FORWARD ENGINEERING

The objective of the third phase of the methodology is to implement the ontology considering the conceptual model from the previous phase [35]. In this research, we used Protégé version 5.0.0 [39] and the reasoner HermiT versión 1.3.8.413 [40] for the inference process of the new ontology.

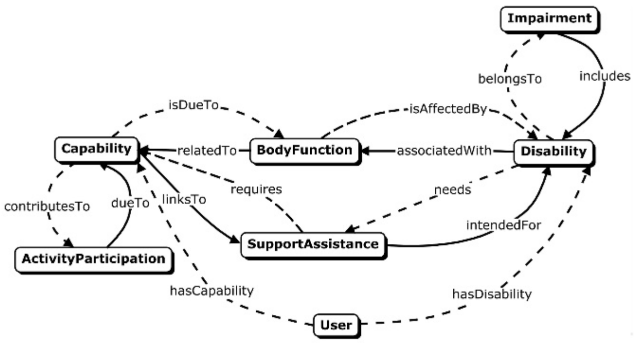

FIGURE 3. Graphical schema of the ACCESIBILITIC ontology.

The new ontology ACCESIBILITIC can be accessed at DOI: 10.21227/r67k-6a29

This consists of 7 classes and 14 relationships. Regarding the instances of these classes, some of them were obtained from the original ontologies, and others were added, specifically when new subclasses were added. The number of instances of each class is: User (28), Impairment (5), Disability (38), Capability (124), BodyFunction (127), ActivityParticipation (27), and SupportAssistance (80).

New instances could be added. Fig. 3 shows the graphical schema of the ACCESIBILITIC ontology.

ACCESIBILITIC was modelled to support the inference process and to answer the following four Competency Questions (CQs):

CQ1: What disabilities belong to each type of impairment?

CQ2: What impairment or combinations of impairment does a user have?

CQ3: What support assistant can be recommended to a user taking into account his/her disabilities and capabilities?

CQ4: What activities and participations can a user perform in the information society according to his/her capabilities?

V. EXPLOITING THE ONTOLOGY: REASONING IN ACCESIBILITIC

In this section we focus on CQ3 to illustrate how it can be answered, more specifically, User_02. To know User_02 better we have the following information of data property "Meet" which specified that:

"Emma (38) is Swedish and grew up in Sollentuna, Stockholm. At birth she suffered neurological damage, causing her to have dysarthria. Emma whispers very softly and produces abnormal intonation when speaking, making it hard for other people to understand her. She also has hearing problems when people or SupportAssistance speak too quickly. Emma works as an independent photographer and regularly gets contracted through her extended network that she built throughout the years. Most of the assignments she takes on are weddings or communions. Emma is also an active helper at the local community centre".

Emma's capabilities are:

–Easy typing, and

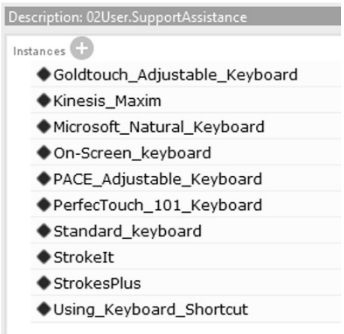

FIGURE 4. Instances inferred for CQ3. Axiom 02User.SupportAssistance.

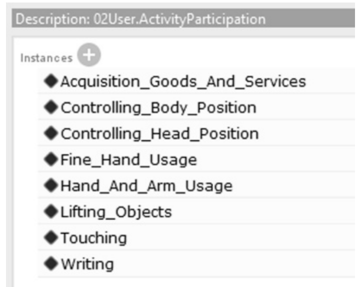

FIGURE 5. Instances inferred for CQ4. Axiom 02User.ActivityParticipation.

TABLE 5. Formal extract of axiom 02user.SupportAssistance.

Axiom name: 02User.Support assistance
Expression:
∀ (?X,?Y,?Z)
[SupportAssistance](?X)and[Disability](?Y)and
[Capability](? Z) → ([intendedFor](?X,?Y)and
[intendedFor](?Y,"Communication_Disability") or
[intendedFor](?Y,"Conductive_Hearing_Loss") or
[intendedFor](?Y,"Expressive_Language_Disorder") or
[intendedFor](? Y, "Dysarthria")
And ([requires](? X, ? Z)and
[requires](? Z, "Easy_Typing")or
[requires](? Z, "Good_Psycomotor_Capability")
Concepts: Support Assistance, Disability, Capability
Binary relationships Ad hoc: intendedFor, requires
Variables: ?X, ?Y, ?Z

–Good psychomotor capability.
Regarding her disabilities, she has:
–Communication disability,
–Conductive hearing loss,
–Expressive language disorder, and
–Dysarthria.

The formal extract of the axiom to answer CQ3 is shown in Table 5.

The reasoner gets the instances shown in Fig. 4 as a response to the previous question.

The result obtained shows technical support from several subclasses of the class SupportAssistance:

–AlternativeKeyboardOrSwitch:
Goldtouch_Adjustable_Keyboard,
Kinesis_Maxim, Microsoft_Natural_keyboard,
On-Screen_keyboard,
PACE_Adjustable_keyboard,
PerfectTouch_101_keyboard and
Standard_Keyboard.
–MouseGestureSupport: StrokeIt and StrokesPlus.
–AdaptiveStrategy: Using_Keyboard_Shortcut.

This example shows the functioning of the ontology to infer information in response to CQ3 with User_02. A quick view of the results for CQ4, with the same user is shown in Fig. 5. The remaining questions can be answered in the same way.

VI. CONCLUSION AND FUTURE WORK

The user model profile allows the characterization of users based on their identified needs, capabilities and limitations. Knowing the user better obviously has an effect on user satisfaction, given the potential improvement of the quality of the user's interactions with information technologies. The user model profile can be implemented through ontologies, because they can make inferences and deduce information. In our proposal we have taking into account the Activity Center Design approach to implement the ontology. Semantic relationships have been included to involve the activities and user profiles to assist developers in the task of choosing the right technology for each activity and how to operate it.

After reviewing several projects and ontologies that deal with semantic modeling in the domain of Accessibility and e-inclusion, we selected knowledge resources such as the ICF classification (which also has an ontology) and the classification of human skills based on ICF. Besides, the following ontologies were selected: User Impairment, ADOLENA, ASKIT, AEGIS/ACCESSIBLE, Affinto, and Egonto. These ontologies allow the identification of common and different aspects among distinct points of view, and allow us to take a closer look at the Accessibility Domain.

Besides, these ontologies emphasize user impairment, disabilities and functional limitations. In contrast, the hierarchy and relationships between the concepts of our new ontology are based on the idea that users can develop a high variety of capabilities despite their disabilities. It is important to highlight that regardless of disability being part of the human condition, people evolve and gain proficiency independently of their limitations.

Our proposal is the ACCESIBILITIC ontology, which consists of the most important concepts in the accessibility Domain according to reused resources. In our ontology, it is possible to organize and unify these concepts to create a hierarchy with an efficient scheme of relationships. The highest level of human activity and the possible range of actions that each user is able to perform, as well as the actions, can be inferred according to how the user's combination of capabilities is represented.

ACCESIBILITIC is the result of a continuous process of reengineering through iterations of reviewed versions, and it is based on the NeOn methodology.

For future work, our vision is that the ACCESIBILITIC ontology can be integrated into a Recommender System to suggest software adaptations and to offer adequate technical support to software developers. On the other hand, specifically for ACD support, we are working on integrating ACCESIBILITIC ontology with an ontology module of CRM application Domain in order to model customers' actions and operations during the CBC. It allows a deeper understanding of how to model effective strategies when thinking about specific customer needs and activities. It is also important to take into account the context in which the activities are performed and to adapt the system accordingly. To this end, Internet of Thing ontologies are useful, because they can capture ambience conditions, as in SOSA or IoT-Lite ontologies. Our ontology can be extended with IoT ontologies.

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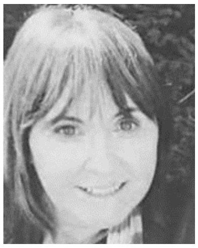

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