A Semantic Data Model of Harmonized Survey on Households Living Standards

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***Abstract*—Since the year 2018, French-speaking countries in West and Central Africa have adopted an identical methodology for collecting household living conditions data through a survey called Harmonized Survey on Households Living Standards (HSHLS). This survey aims specifically at gathering information on socio-economic conditions of households and communities, enabling public authorities and development partners to identify areas where necessary solutions can be provided. The related questionnaire for this survey, intended to be administered electronically in the form of Computer-Assisted Personal Interview (CAPI) using tablets and telephones, helps reduce errors during data collection because some data consistency checks are managed automatically through the data collection application used, based on a set of prior real-world information. However, during data cleaning works, discrepancies are sometimes observed between the methodology and the actual collected data. Moreover, data processing teams are often forced to manually check methodologic documents for analysis purposes. In this paper, we design a semantic model, which represents the information contained in the methodological documents related to the survey under study. This model, based on an ontology built using Resource Description Framework (RDF) language and its extension, RDF Schema, allows documenting knowledge related to this survey in the form understandable by computers and easily queryable.**

Keywords-knowledge documentation; semantic data modeling; RDF ontology; Methodological information; Harmonized Survey on Households Living Standards.

I. INTRODUCTION

The Harmonized Survey on Households Living Standards (HSHLS) [1] is a household survey consisting of a set of modules or sections, each section dealing with a given theme. Among the topics addressed there are: the socio-demographic characteristics of households and their members as well as information on education, health and employment of household members. Information about each section is collected through a specific questionnaire administered using a computer application. The collected data is usually stored in a tabular structure in a relational database. After the data collection operations are executed, they are retrieved in Excel-type files for possible analyses. During data cleaning operations, discrepancies are often found between the methodology and the data actually collected, as some of the collected data do not comply with the conditions or rules defined in the methodology. Moreover, since the methodological information is not automated, data processing teams are often forced to manually consult the related documents; this sometimes causes delays in the data processing procedures. It is in this context that the present research work is conducted, aiming to develop a semantic modeling approach to represent the methodological information of the survey under study. Ultimately, the developed model will facilitate the search for methodological information and serve as a foundational tool for automatic quality control of the real data from this survey. Since the HSHLS is a major statistical survey conducted by several African countries, our motivation is to document and disseminate knowledge related to this survey to make it accessible to a wide audience.

Our paper is structured as follows: In Section II, we define the concept of semantic data modeling and its advantages. In Section III, we present the literature review related to the semantic modeling in statistical surveys and highlight some limitations of the state of the art. Section IV presents the adopted methodology and tools. In Section V, we present our model and the implementation details. In Section VI, we present and discuss the results. Finally, we end with a conclusion along with an outline of potential future work, in Section VII.

II. SEMANTIC DATA MODELING

Data semantics is the meaning given to that data; it is its significance. It encompasses all the information that can be gathered about the data with respect to a specific objective and a particular reality. For example, regarding the data point Age, the following information can be inferred: Age is a property of a person, that defines their current lifespan, expressed in years, which is the mathematical difference between the year of birth and the current year, taking into account the date of the person's most recent birthday. This lifespan is an integer between 0 (minimum duration) and 120 (maximum duration). The year of birth and the current year

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are also properties of a person, of integer type. Semantic data modeling involves representing the data and their semantics as well as the relationships between them.

Semantic data models play a crucial role in the modeling of complex knowledge. They allow representing relationships and interactions between concepts in an accurate and structured way. These models are used in various application scenarios: representing relationships between concepts, encapsulating business knowledge, data search and analysis, integrating heterogeneous data sources, and supporting artificial intelligence and machine learning.

III. LITERATURE REVIEW

In the context of semantic modeling applied specifically to statistical survey data, the following research has strongly influenced our work.

The work in [2] addresses the challenge faced by users who need to write complex database queries to retrieve information, given their limited understanding of both the structural and semantic complexities of databases. It focuses on improving this process through the use of ontologies to facilitate better knowledge representation and interactive query generation.

Thirumahal et al. use an ontology-based approach to develop a semantic model for harmonizing and integrating population health data from heterogeneous sources [3]. Following a presentation of the ontology literature, the authors of [3] identified key concepts and relationships between population health data. Then, they used this information to develop an XML schema-based semantic ontology to harmonize and integrate population health data from different sources (Excel, SQL Server and MongoDB) for early detection of COVID-19. The authors state that the model designed allows data to be inserted, updated and deleted without anomaly as the data mapping is based on schema and not on data. The authors also state that in the future, their method could be extended by creating ontologies in RDF/Turtle formats.

Berges et al. propose an approach to improve the semantic interoperability of electronic health records using ontological management of domain ontology evolution [4]. The researchers first developed a domain ontology representing concepts and relationships relevant to the domain of electronic health records. Then, they proposed methods to manage the evolution of this ontology over time, taking into account changes in the electronic health domain and new data requirements.

In [5], Nicholson et al. use an ontology-based approach to ensure a good level of data quality for cancer-related information in registries, in order to accurately compare indicators related to this disease on regional and national scale based on harmonized rules.

The work in [13] introduces a generic ontology designed to represent questionnaires in a machine-readable format. This ontology aims to enhance decision support systems and smart environments by facilitating automatic processing of questionnaire data, which has become more abundant and cost-effective due to mobile devices. It addresses the challenge of managing and reasoning about large volumes of collected information to gain deeper insights.

Considering the literature review, we notice that there is a great deal of similar work in semantic data modeling. However, to the best of our knowledge, there is no application of these research studies to the statistical harmonized housing surveys on household living standards. Access to methodological information is manual and the majority of data quality control is conducted manually, leading to significant delays in data processing. Therefore, our contribution lies in the application of this work in the context of documentation and popularization of knowledge relating to the HSHLS survey and consists in proposing a semantic data model whose use would among other things, facilitate access to related knowledge and help speed up data processing.

IV. METHOD AND TOOLS

A. Methodology

The literature review led us to adopt an ontology-based semantic modeling approach to represent and structure knowledge semantically. This choice is justified by the fact that:

- Ontologies enable complex logical relationships between concepts to be defined formally. Axioms and rules can be used to express logical conditions of dependency between survey questions such as IF-THEN conditions, validation constraints, hierarchical relationships, etc.
- Ontologies provide a standardized, shared data model, promoting interoperability between different systems and enabling easier data integration. This can be particularly useful in a survey context, where data needs to be collected, stored and analyzed in a consistent and standardized way.
- Ontologies enable the complexity of dependencies between survey questions to be managed in a structured way. Concepts can be organized into classes and sub-classes and properties and restrictions can be defined, making it easier to manage and understand the relationships between different questions.
- Ontologies provide a solid basis for managing the evolution and maintenance of the semantic data model. Concepts and relationships can be easily added, modified or deleted without compromising model consistency and compatibility.

B. Tools

Although there are many works available in the literature that use other representation ways, to build our semantic model, represent concepts and their relationships, the Resource Description Framework (RDF) language is used in this paper.

RDF is a language standardized by the World Wide Web Consortium (W3C) to represent information on the Web in a

structured and interoperable way. It provides a simple data model based on subject-predicate-object assertions, also known as RDF triples. Each triple describes a relationship between two resources [6].

RDF Schema (RDFS) is an extension of RDF that provides a vocabulary for describing schemas and ontologies. This enables the definition of classes, properties and relationships between RDF resources [7].

To learn about the various concepts related to the survey under study as well as the relationships between the data, this research relies on methodological documents including household questionnaires, interviewer manuals and survey data dictionaries.

Our semantic model is built using RDF and RDF Schema. We propose to use metamodeling techniques to implement the models needed to manipulate the elements of the Harmonized Survey on Households Living Standards questionnaire and the survey data consistency control. The following section presents our semantic model.

V. MODELIZATION AND IMPLEMENTATION

A. Definitions of key concepts

1) Harmonized Survey on Households Living Standards(HSHLS): HSHLS is the main harmonized statistical survey conducted by French-speaking countries in West and Central Africa to capture household living conditions.

2) Section: The HSHLS survey is composed of sections. A section is named according to the topic addressed: Socio-demographic characteristics, Education, Health, etc.

3) Questionnaire: Every section has a single questionnaire. A questionnaire captures the main information of surveyed households related to a given section.

4) Question: A questionnaire is composed of questions.

5) Household: This is the main statistical unit on which information are gathered.

6) Household member: A person belonging to a particular household.

B. Presentation of the HSHLS metamodel

Our model consists of a resource class HSHLS representing HSHLS surveys, an instance of the rdfs:Class class of the RDF metamodel. A survey is made up of sections. A section contains a questionnaire. A questionnaire concerns a household, and a questionnaire is of a certain type, depending on the information collected. This may be information characterizing household members or common household characteristics. These characteristics are variables represented by questions. Each question is a property in our model and concerns a household member or a household as a whole. A question belongs to a type (integer, float, string) depending on the nature of the expected response. Each question is linked to a questionnaire. A question may depend on other questions and may have constraints.

The general metamodel includes the class declaration metamodel (Figure 1) and the property declaration metamodel (Figure 2). More details of the semantic model are given in the Appendix. In the class declaration, the declaration C rdf:type C' means that the class C is an instance of the class C'. For example, hshls:HSHLS rdf:type rdfs:Class states that the HSHLS is an instance of rdfs:Class. In the property declaration, a triple of the form: P rdfs:domain C declares that P is an instance of the rdf:Property class, that C is an instance of the rdfs:Class class, and that the resources indicated by the subjects of triplets whose predicate is P are instances of the C class. This implies that hshls:hasQuestion rdfs:domain hshls:Questionnaire states that hasQuestion is an instance of rdf:Property class, Questionnaire is an instance of the rdfs:Class class, and that the resources indicated by the subjects whose predicate is hasQuestion are instances of the class Questionnaire. The triple P rdfs:range C means that P is an instance of the rdf:Property class, that C is an instance of the rdfs:Class class, and that the resources indicated by the objects in the triple whose predicate is P are instances of the C class. In this case, hshls:hasQuestion rdfs:range hshls:Question means that hasQuestion is an instance of the rdf:Property class, Question is an instance of the rdfs:Class class, and that the resources indicated by the objects in the triple whose predicate is hasQuestion are instances of the Question class.

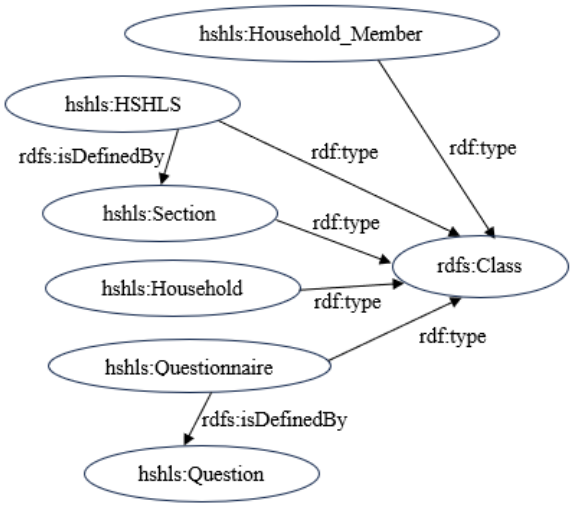

Figure 1. HSHLS RDFS metamodel with class declaration.

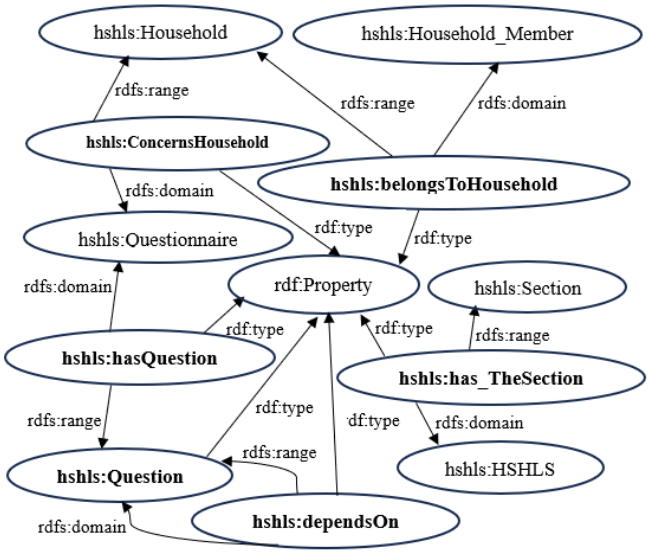

Figure 2. HSHLS RDFS metamodel with property declaration.

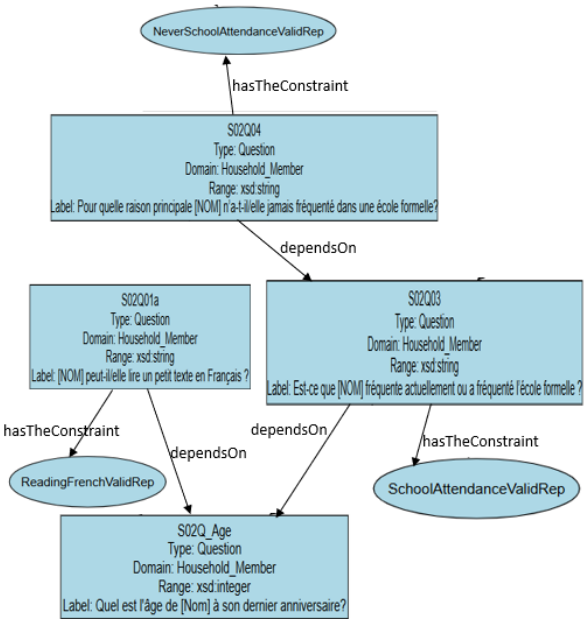

Figure 3. The HSHLS RDFS Ontology with actual questions.

C. *HSHLS model specialization*

The HSHLS has 21 sections. To serve as a proof of concept, we propose a specialization of our metamodel, considering personalized methodological information used during the first edition of this survey in Congo. We do consider a particular section of the survey: the Education section. The specialization is as follows:

1) HSHLS ontology with actual questions: Figure 3 illustrates the map of HSHLS ontology with actual questions and their dependencies and constraints, for the section which captures education's information, coded S02. This section has a single questionnaire, Questionnaire2. Questionnaire2 will be instantiated for every surveyed household. The education information concerns household members of three (3) years old or above. So the entry in this questionnaire depends on the response to the question on the age of the corresponding household member surveyed, here coded S02QAge. The question S02Q1a captures whether the surveyed household member can read a little text written in French. S02Q1a depends on the question S02QAge. An illustration of dependency conditions between questions is presented in Figure 5. The question S02Q03, which also depends on the question S02QAge, captures whether the surveyed household member is currently attending or have attended a formal school. The question S02Q04 captures the reason why the surveyed household member has never attended a formal school. S02Q04 depends on the response to the question S02Q03 which can be "Oui" (for Yes) or "Non n'a jamais fréquenté" meaning that the concerned surveyed has never attended a formal school. S02Q04 is asked only if the response to S02Q03 takes the second valid value. An illustration of constraints specification on questions is given in Figure 4.

2) HSHLS ontology constraints specification: The triples hshls:ReadingFrenchValidRep rdf:type hshls:Constraint and hshls:SchoolAttendanceValidRep rdf:type hshls:Constraint mean that ReadingFrenchValidRep and SchoolAttendanceValidRep are instances of Constraint class. The constraint ReadingFrenchValidRep specifies that the valid values of the related question (S02Q01A) are "Oui" (for Yes) or "Non" (for No). The constraint SchoolAttendanceValidRep indicates the valid values of the related question (S02Q03).

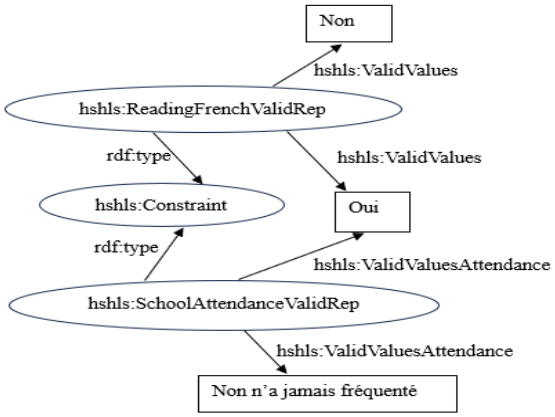

Figure 4. HSHLS RDFS Ontology constraints specification.

3) HSHLS ontology dependency specification: Figure 5 indicates that the question S02Q01a depends on the question S02QAge and the dependency condition is that the value of S02QAge (which precedes S02Q01a) must be greater or equal to 9. That means, to ask the question S02Q01a, the concerned surveyed must be 9 years old or above. If this condition is not satisfied, then the property S02Q01a must be empty for the concerned surveyed.

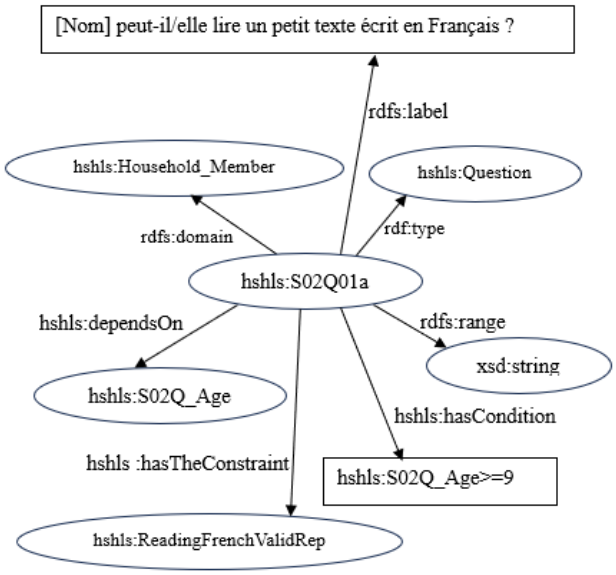

Figure 5. HSHLS ontology dependency specification.

We built the proposed model using the Python RDFLib package [8], in a Jupyter notebook environment. The model is saved in Turtle (ttl) format and can be exploited as an RDF graph. To make it possible to get access to the model in a persistent way, we defined an International Resource Identifier (IRI) for the model. We also developed an HTML ontology documentation file using PyLODE [9]. We created a public Github repository [10] and saved the rdf graph and its HTML documentation in it.

VI. RESULTS AND DISCUSSION

This model makes it possible to store the methodological information of the Harmonized Survey on Households Living Standards in such a way that it can be understood by the computer and retrieved automatically. By specifying the semantics of the questions addressed, this model helps to better understand the meaning of the data manipulated in this survey as well as the semantic relationships that exist between these data. With the specification of some constraints and conditions on related questions, this model can serve as a fundamental tool for data quality control on actual data during data collection and processing. Since the model is saved in a persistent repository, one can easily get access and perform some retrievals and analysis requests using SPARQL [11] or any appropriate data analysis tool. Also, a large audience can get access and learn related knowledge. Therefore, the project will not only help improving the efficiency during the survey data collection and processing activities, but also contributes to the dissemination of the survey knowledge.

VII. CONCLUSION AND FUTURE WORK

In this work we propose an approach to semantic data modeling of the Harmonized Survey on Households Living Standards. The model built makes it possible to store the semantic information contained in the methodology of this survey so that it can be consulted automatically. The results of this work can therefore be exploited as part of the automatic retrieval of methodological information. Generally speaking, this work completes the state of the art and serves as a proof of concept to demonstrate the feasibility of documenting the knowledge contained in a statistical survey questionnaire through ontology-based semantic modeling. Researchers from a variety of backgrounds will find it a source of information when it comes to design approaches requiring ontology-based semantic modeling of data, whether statistical survey data or not.

This model highlights semantic information derived from the methodology of the Harmonized Survey on Households Living Standards. To enable automatic data quality control based on this model, an extension of the model will be developed in the future with complex constraints and conditions, using OWL2 [12] or another equivalent language that we will study, which is complementary to and interoperable with RDF. An automatic reasoning engine will be built for the purpose of anomaly detection in actual data.

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APPENDIX

Here is a part of the semantic model of the Harmonized Survey on Households Living Standards:

```
@prefix hshls: <http://w3id.org/HshlsOnto/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix  rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs:<http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd:<http://www.w3.org/2001/XMLSchema#> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix vann: <http://purl.org/vocab/vann/> .
hshls: a owl:Ontology;
   rdfs:seeAlso "https://github.com/moukmarc/HshlsOnto" ;
   dcterms:creator "Marc Mfoutou Moukala" ;
   dcterms:title "Harmonized survey on household living standards Ontology (HshlsOnto)" ;
   vann:preferredNamespacePrefix "hshls" .
# Core classes declaration
hshls:HSHLS a rdfs:Class ;
   rdfs:isDefinedBy hshls:Section ;
   rdfs:label " Harmonized Survey on Households Living Standards" .
hshls:Section rdf:type rdfs:Class ;
        rdfs:label " A section or module of the survey " .
hshls:Questionnaire rdf:type rdfs:Class ;
        rdfs:isDefinedBy hshls:Question .
hshls:Household a rdfs:Class ;
   rdfs:label " A household " .
hshls:Household_Member rdf:type rdfs:Class ;
   rdfs:label " A household member surveyed " .
hshls:Constraint rdf:type rdfs:Class ;
      rdfs:label " Constraint on the question " .
# Property declaration
hshls:ccontainsQuestionnaire a rdf:Property ;
 rdfs:domain hshls:Section ;
 rdfs:range hshls:Questionnaire ;
   rdfs:label "contains questionnaire" .
hshls:ConcernsHousehold a rdf:Property ;
   rdfs:domain hshls:Questionnaire ;
   rdfs:range hshls:Household ;
   rdfs:label " Concerns household " .
hshls:typeOfQuestionnaire a rdf:Property ;
   rdfs:domain hshls:Questionnaire ;
   rdfs:range rdfs:Literal ;
   rdfs:label " type of questionnaire " .
hshls:Question a rdf:Property ;
   rdfs:label " A question relating to the survey " .
hshls:belongsToHousehold a rdf:Property ;
   rdfs:domain hshls:Household_Member ;
   rdfs:range hshls:Household ;
   rdfs:label " belongs to household " .
hshls:hasTheSection rdf:type rdf:Property ;
        rdfs:domain hshls:HSHLS ;
        rdfs:range hshls:Section ;
        rdfs:label " Includes section " .
hshls:hasQuestion rdf:type rdf:Property ;
        rdfs:domain hshls:Questionnaire ;
        rdfs:range hshls:Question ;
        rdfs:label " Includes question " .
hshls:hasTheTypeOfResponse rdf:type rdf:Property ;
        rdfs:domain hshls:Question ;
        rdfs:range xsd:string ;
        rdfs:label " has the question answer type " .
hshls:hasTheConstraint rdf:type rdf:Property ;
      rdfs:domain hshls:Question ;
      rdfs:range hshls:Constraint ;
      rdfs:label " has the constraint " .
hshls:dependsOn rdf:type rdf:Property ;
      rdfs:domain hshls:Question ;
      rdfs:range hshls:Question ;
      rdfs:label " depends on " .
hshls:hasCondition rdf:type rdf:Property ;
      rdfs:domain hshls:Question ;
     rdfs:range xsd:string ;
     rdfs:label " has the condition " .
# Constraint Classes
hshls:NumericConstraint rdf:type rdfs:Class ;
         rdfs:subClassOf hshls:Constraint ;
         rdfs:label "Numeric constraint" .
# Constraint Properties
hshls:minValue rdf:type rdf:Property ;
      rdfs:domain hshls:NumericConstraint ;
      rdfs:range xsd:float ;
      rdfs:label "Minimum value" .
hshls:maxValue rdf:type rdf:Property ;
      rdfs:domain hshls:NumericConstraint ;
      rdfs:range xsd:float ;
      rdfs:label "Maximum value" .
# Model specialization
```

hshls:HSHLS-C1 rdf:type hshls:HSHLS ;
hshls:hasTheSection hshls:S00, hshls:S01, hshls:S02, hshls:S03, hshls:S04, hshls:S05, hshls:S06, hshls:S07,
hshls:S08, hshls:S09, hshls:S10, hshls:S11, hshls:S12, hshls:S13, hshls:S14, hshls:S15, hshls:S16, hshls:S17,
hshls:S18, hshls:S19, hshls:S20, hshls:S21 ;
rdfs:comment "The different sections of HSHLS survey for the first edition in Congo named here HSHLS-C1" .
hshls:S02 a hshls:Section ;
hshls:ccontainsQuestionnaire hshls:Questionnaire2 ;
rdfs:comment "Every HSHLS section contains one questionnaire, which will be instanciated for every surveyed household" .
Questionnaires in section S02
hshls:Questionnaire2 a hshls:Questionnaire ;
hshls:typeOfQuestionnaire "Household member's education information" ;
hshls:ConcernsHousehold hshls:Household ;
hshls:hasQuestion hshls:S02Q_Age, hshls:S02Q01a, hshls:S02Q01b, hshls:S02Q01c, hshls:S02Q01d,
hshls:S02Q02a, hshls:S02Q02b, hshls:S02Q02c, hshls:S02Q02d, hshls:S02Q03a, hshls:S02Q03b, hshls:S02Q03c, hshls:S02Q03d, hshls:S02Q04, hshls:S02Q05, hshls:S02Q06, hshls:S02Q07, hshls:S02Q08, hshls:S02Q09, hshls:S02Q10, hshls:S02Q11, hshls:S02Q12, hshls:S02Q13, hshls:S02Q14, hshls:S02Q15, hshls:S02Q16,
hshls:S02Q17, hshls:S02Q18, hshls:S02Q19, hshls:S02Q20, hshls:S02Q21 ;
rdfs:comment "The Questionnaire2 captures household member's education information for members of 3 years old and more" .
Questions of Questionnaire2
hshls:S02Q_Age a hshls:Question ;
rdfs:domain hshls:Household_Member ;
rdfs:range xsd:integer ;
rdfs:label "Quel est l'âge de [Nom] à son dernier anniversaire?" ;
rdfs:comment "The question S02Q_Age captures the age of the surveyed household member" ;
rdfs:subClassOf [
a rdfs:Datatype ;
rdfs:subClassOf xsd:integer ;
rdfs:minInclusive "0"^^xsd:integer ;
rdfs:maxInclusive "120"^^xsd:integer
] .
hshls:S02Q01a rdf:type hshls:Question ;
rdfs:domain hshls:Household_Member ;
rdfs:range xsd:string ;
rdfs:label "[NOM] peut-il/elle lire un petit texte en Français ?" ;
hshls:hasTheTypeOfResponse "String" ;
hshls:dependsOn hshls:S02Q_Age ;
hshls:hasCondition "(hshls:S02Q_Age >= 9)" ;
hshls:hasTheConstraint hshls:ReadingFrenchValidRep ;
rdfs:comment "This question captures whether the surveyed household member can read a little text written in french" .
hshls:S02Q03 rdf:type hshls:Question ;
rdfs:domain hshls:Household_Member ;
rdfs:range xsd:string ;
rdfs:label "Est-ce que [NOM] fréquente actuellement ou a fréquenté l'école formelle ?" ;
hshls:hasTheTypeOfResponse "String" ;
hshls:dependsOn hshls:S02Q_Age ;
hshls:hasCondition "(hshls:S02Q_Age >= 3)" ;
hshls:hasTheConstraint hshls:SchoolAttendanceValidRep ;
rdfs:comment "This question captures whether the surveyed household member is currently attending or have attended a formal school" .
hshls:S02Q04 rdf:type hshls:Question ;
rdfs:domain hshls:Household_Member ;
rdfs:range xsd:string ;
rdfs:label "Pour quelle raison principale [NOM] n'a-t-il/elle jamais fréquenté dans une école formelle?" ;
hshls:hasTheTypeOfResponse "String" ;
hshls:dependsOn hshls:S02Q03 ;
hshls:hasCondition "(hshls:S02Q03 = Non n'a jamais fréquenté)" ;
hshls:hasTheConstraint hshls:NeverSchoolAttendanceValidRep ;
rdfs:comment "This question captures the reason why the surveyed household member has never attended a formal school" .
Constraint for valid responses for the question S02Q01a
hshls:ReadingFrenchValidRep a hshls:Constraint ;
hshls:ValidValues "Oui","Non" .
Constraint for valid responses for the question S02Q03
hshls:SchoolAttendanceValidRep a hshls:Constraint ;
hshls:ValidValuesAttendance"Oui","Non n'a jamais fréquenté" .
Constraint on S02Q04 for valid responses why the surveyed never attended a formal school
hshls:NeverSchoolAttendanceValidRep a hshls:Constraint ;
hshls:ValidValuesNeverAttendance "Trop jeune (moins de 6 ans)", "Pas d'école, école trop éloignée", "Refus de la famille","Préférence pour un emploi", "Travaux champêtres/pastoralisme", "Travaux domestiques", "Mariage", "Renvoi", "Frais de scolarité élevés", "Manque de moyens financiers", "Etudes non adaptées", "Etudes peu utiles", "Malade", "Pas d'acte de naissance", "Handicap", "Insécurité", "Autre (à préciser)" .