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An Adaptive Land Tenure Information System Database Design for Conflict and Post-Conflict Situations

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An Adaptive Land Tenure Information System Database Design for Conflict and Post-Conflict Situations

by

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Abstract

The key objective of this study was to design, develop, and test a schema-less graph network Land Tenure Information System (LTIS) database prototype that is integrated with data mining and social network analysis techniques for the purpose of revealing hidden tenure information in the data related to conflict and post-conflict situations. Conventional LTISs are ineffective in conflict and post-conflict situations because they only describe recorded tenure information, and therefore these systems are not reflective of land practices taking place on the ground. In conflict and post-conflict situations, multiple sets of state held and privately held land tenure records may exist. The question then is how can LTISs be better designed to capture and describe tenure information in conflict and post-conflict situations. The study adapts a spiral software development model to develop a Talking Titler Network (TTN) database prototype. Simulated tenure data from two illustrative cases was entered and automatically mined and analysed within the database system. The results show that a schema-less graph network database integrated with data mining and social network analysis techniques can capture and describe complex land tenure information among and between people and tenure objects. In addition, the integrated techniques automatically extract, investigate, and visualise embedded tenure information emerging from these situations. The experimental test results provide important empirical observations to advance the TTN database design and development in order to assist in supporting land tenure dispute resolution for conflict and post-conflict situations. However, further field work needs to be carried out to validate the results.

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Finally, I am deeply indebted to my family and friends for their patience, love, and encouragement. They are in my heart always. To my Canadian family, Elizabeth, Richard, and Allison, thank you for supporting me and for treating me like a family member.

Dedication

I dedicate this thesis to the holy land, my homeland Palestine; the home of my ancestors. In the words of Mahamoud Darwish, “We have on this land what makes life worth living. Peace to the land that was created for peace, and never saw a peaceful day.” I also dedicate this work to Canada, my second home, and the country that has given me opportunities beyond my wildest dreams.

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List of Glossary of Terms Abbreviations

Symbol	Definition
CPCLTL	Conflict and Post-Conflict Land Tenure Ladder
GIS	A Graphic Information System
GUI	A Graphical User Interface
IDPs	Internally Displaced People
ISO	International Organization for Standardization
Land	"Property is a social and juridical institution, a commonplace in the anatomy of all civilised societies. In human relationships it is a vehicle of power and in the land context a determinant of the occupation, possession and ownership of land" (Denman, 1978, p. 2)
LTIS	Land Tenure Information System
Non-RDBS	Non-Relational Database System
OWL	Web Ontology Language
RDBS	Relational Database System
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
Rich description	Explicit and implicit tenure information
Social matrix	"[C]omprises those aspects of social organisation which uphold the land tenure system and the social actions which may change a system. These

	are the relations between people, what may be termed the man-man relations (Barry and Fisher 2015)."
STDM	Social Tenure Domain Model – the system was developed by UN-Habitat to support land tenure in slum areas.
TTN	Talking Titler Network – the system was developed by the author to support tenure security in conflict and post-conflict situations.
TTS	Talking Tilter System – the system was developed by the Land Tenure and Cadastral Systems research group at the University of Calgary to support tenure security in complex and uncertain situations.

Chapter One: Introduction

1.1 Introduction

Conventional Land Tenure Information Systems (LTISs), such as systems which register real property rights, are seldom designed to support land tenure security in conflict and post-conflict situations (Muhsen 2008; Barry 2008d). At times, these systems do more harm than good and may exacerbate situations by misrepresenting, or omitting significant tenure relationships (Muhsen 2008; Barry 2008d). This may threaten the tenure security of vulnerable people in a society. Therefore, these systems often fail to support land tenure security in conflict and post conflict situations (Muhsen 2008).

Land tenure security in conflict and post-conflict situations tends to deteriorate as a result of the impacts of multifaceted problems: social change characteristics, undocumented civil concerns, and internal and external conflicts (Wehrmann 2008; UN-Habitat 2012). Within this research context, internal conflicts refer to disputes among members within a family or a clan. External conflicts refer to disputes between different clans/groups affected by an external force such as a political party, a military, and a foreign country. In conflict and post-conflict situations, which may be characterised by internal conflicts, external conflicts, or internal and external conflicts, people may not register their property and/or are susceptible to loss of land tenure documentation.

In the absence of documentation, claims can be solved through social negotiation processes. A flexible LTIS can capture and describe tenure information in a way to assist the social negotiation process, securing tenure, improving the level of equity, and aiding in settling land disputes, especially in cases where land serves as the primary driver of conflict (Unruh 2016).

This thesis argues that applying a schema-less design model to develop a graph network LTIS database with built in data mining and social network analysis techniques provides the flexibility to capture and describe complex tenure relationships characterising conflict and post-conflict situations. The built in data mining and social network analysis techniques integrated in the schema-less graph network database design should aid stakeholders engaged in tenure conflict resolution processes by automatically revealing hidden tenure relationships, and, investigating the social matrix (Asiedu 2014). The proposed database design intends to improve land tenure security and ultimately promote regional stability. Therefore, this research proposes an adaptive LTIS database prototype in the context of conflict and post-conflict situations. The Palestinian Territory, an ongoing conflict situation, and the Somaliland region, a post-conflict situation, provide the illustrative contexts for this experimental work.

The goal of this research is to contribute to design theory which is understood in this study as referring to “a normative or prescriptive type of theory – it gives guidelines or principles that can be followed in practice” (Gregor 2002, p. 17). In this research, the proposed LTIS database was described using Gregor and Jones’ design theory framework (Gregor and Jones 2007 p. 322). From the framework, several components were purposely chosen for the context of the design objectives, and then applied without iterations (i.e. the software was designed and tested without field trials and redesign). The design theory framework consists of eight components: *purpose and scope, constructs, principles of form and function, artifact mutability, testable propositions, justificatory knowledge, principle of implementation, and expository instantiation* (Gregor and Jones 2007, p. 322). The author used the components that were relevant to the proposed LTIS database design description. The study contributes to design theory by showing that it is possible to improve the functional component of a LTIS database system in conflict and post-conflict situations by designing, developing, and testing a schema-less graph network database that is integrated with data mining and social network analysis techniques.

1.2 Problem Statement

Expanding on the introduction paragraph, conventional LTISs are inadequate in supporting tenure security in unstable situations, specifically conflict and post-conflict situations (Muhsen 2009; Asiedu 2014). First, conventional LTISs are too rigid for these situations as tenure relationships become dynamic and fluid in conflict and post-conflict conditions (Barry and Bruyas 2007). Conventional LTISs are designed for contexts that are different from conflict and post-conflict situations. In such situations, land disputes are often multifaceted and can change according to varying political and social influences. For example, customary law may influence an inheritance dispute involving different families, extended families, sub-clans, and/or clans from different generations. As changes in land ownership go unreported, discrepancies are created between state held and privately held records (Barry 2006; Muhsen and Barry 2008; UN-HABITAT 2012). Discrepancies may occur in the aforementioned situations for a number of reasons. For example, land tenure information is not secure as people may lose documentation, title documents and deeds, during the conflict (Herrera and Passano 2006; Unruh 2016). In such circumstances, conventional LTISs can only reflect recorded information that may not be fully representative of changes on the ground.

Second, conventional LTISs struggle to manage (*e.g.* capture and depict) land disputes in conflict and post-conflict situations because most of these systems were developed based on Western concepts of procedural law (Schiffman, 2006). In conflict and post-conflict situations, people may not follow procedural law, but adopt their own procedures to resolve land disputes.

They may follow procedures based on familial and cultural customs. In these situations, there is a noticeable gap between *de facto* and *de jure*, which worsens the situation and encourages practices such as land grabbing (Larson 2012, p. 30). As different groups and individuals adopt their own means to address land disputes, conventional LTISs struggle to keep up with land changes in conflict and post-conflict situations. Last, in certain cases, conventional LTISs exacerbate the *de facto* situation by misrepresenting significant linkages between particular items of information stored in the system (Barry n.d).

A conflict situation is complex and it may be difficult to fully understand the land problems at hand due to interrelationships between behaviours on the ground and various interwoven factors, such as political and social factors that are not clearly apparent. For example, in conflict situations such as in Palestine and Syria, an enormous number of refugees became displaced and did not have the time to collect their tenure documents and evidence prior to their evacuation. Moreover, in ongoing conflict situations, complexity is increased in part by the invasion of land and property, forceful evictions, informal settlements and the assumption of authority by illegitimate groups and individuals (ODI 2009; Koek et al. 2015; Unruh 2016).

In post-conflict situations, land and property restitution claims rise when people return to their places of origin and use whatever available documents as evidence to assert their ownership claims. More recently, refugees use the available online technologies and engage in online social network applications (*e.g.* Facebook, Twitter, and WhatsApp) in order to follow up, transfer, and collect evidence about their properties and land objects (Unruh 2016). On one hand, this type of information can be contested; on the other hand, this type of information can be helpful for supporting tenure claims as it can be used as data. These documents are mostly informal papers, pictures, recorded videos or audio, scenarios from neighbours, and whatever information that can be collected from online applications to assist in supporting their claims. As official ownership documents are not always readily available to secure property, restitution is a problematic issue for peace-building and recovery efforts following conflict (Muhsen and Barry 2008; Unruh 2016).

The following two subsections describe two illustrative cases for conflict and post-conflict situations, Palestine and Somaliland, respectively.

1.2.1 Palestine (the Palestinian Territory)

The Palestinian Territory which refers to the areas under the Palestinian National Authority's control outlined in the Oslo Accords. In Palestine, around five million Palestinian refugees are living in and within United Nations camps due to internal and external conflicts (UNRWA 2016). The main cause of these conflicts is land, making land tenure security a crucial factor in conflict resolution, and reconstruction and development efforts (Ministry of Planning 2008; UNRWA 2016). In the latter, land ownership documents are necessary for property reconstruction processes undertaken by the government and its partners. However, this is problematic because of inadequate government records of land ownership. For example, the 2014 war between Israel and Gazan fighters led to the destruction of approximately 16,000 houses and displaced more than 117,000 Palestinians (Koek et al. 2015). Reconstruction efforts after this war were hampered by the fact that approximately 70% of private lands in the Gaza Strip are not registered (Koek et al. 2015). The challenge of the reconstruction process is identifying the rightful landowners and resolving property disputes. This research focuses primarily on the land disputes found between families, sub-families, extended families, clans, and sub-clans living in the Palestinian Territory, more specifically the Gaza Strip.

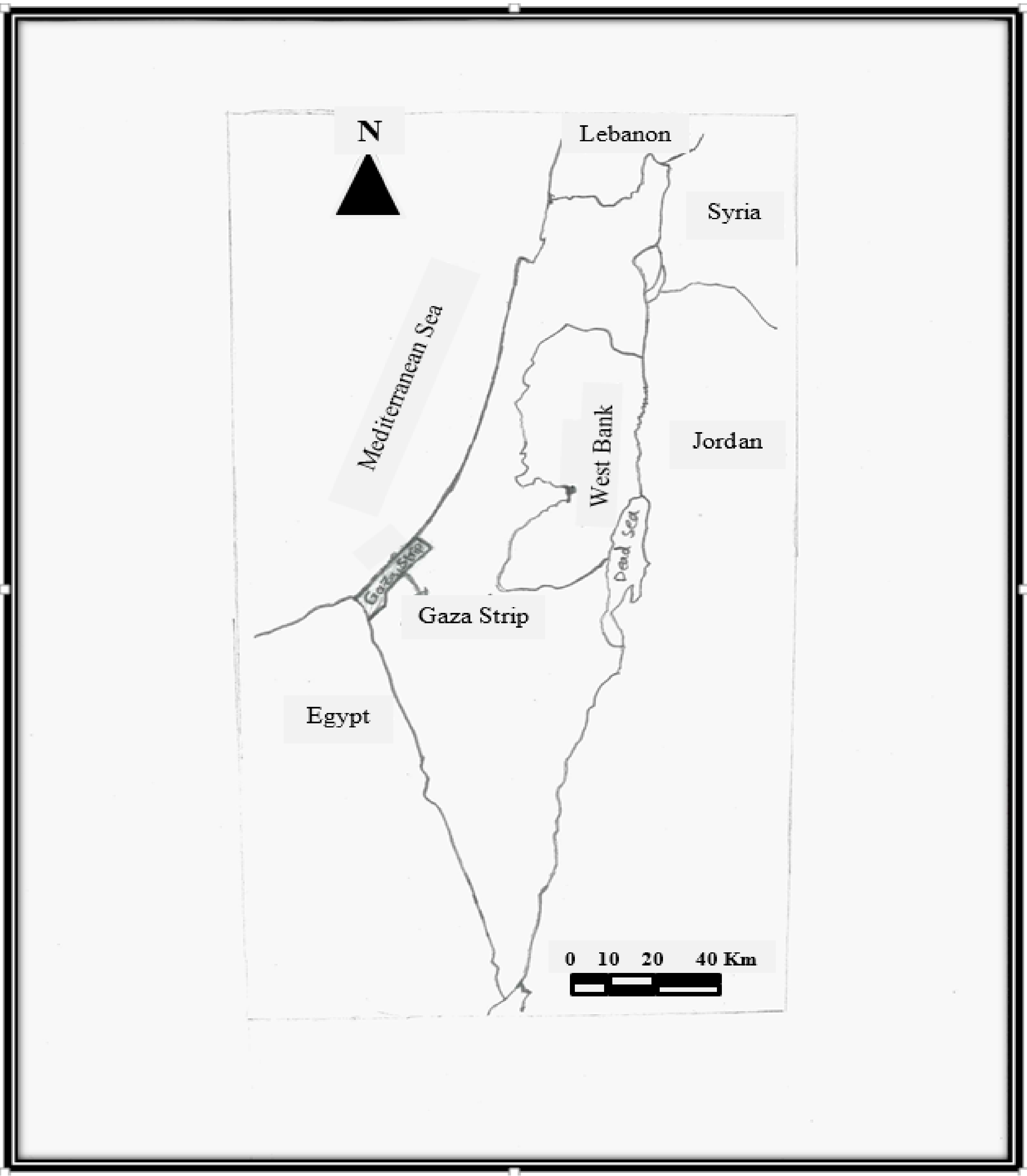

Figure 1.1. The map of Palestine/Palestinian Territory (Abu-Sitta 2010)

1.2.2 Somaliland

Between 1988 and 1990, civil war took place in Somalia. About 500,000 people fled their houses to escape violence, and 40,000 people were killed during the conflict (Barry 2006). In 1991, the northwestern region of Somalia, i.e., Somaliland, unilaterally seceded from Somalia. However, this unilateral declaration of independence has yet to be recognized by the international community (Barry 2006).

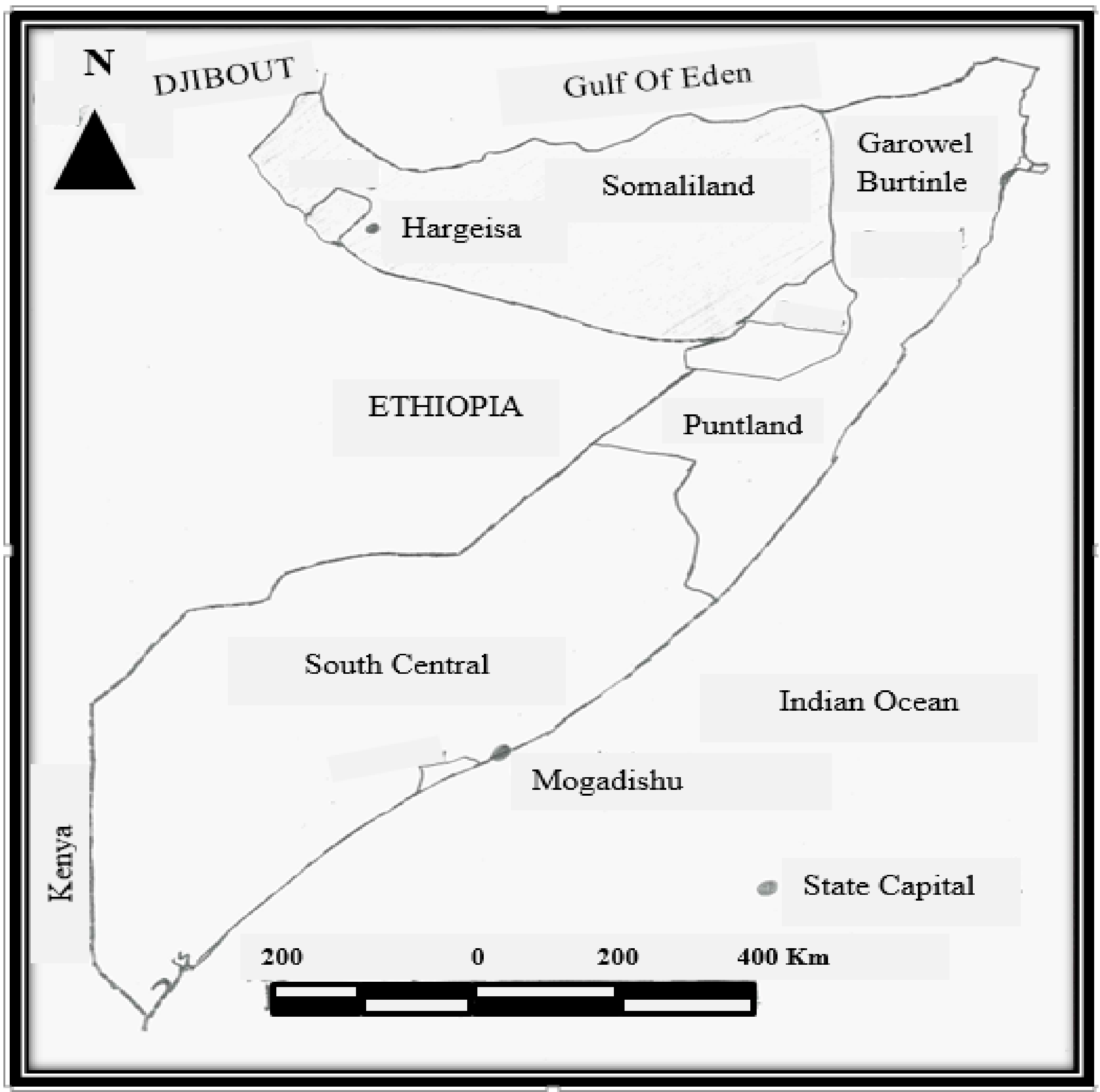

Figure 1.2. The map of Somaliland (Noor 2016)

After the civil war subsided, the capital of Somaliland, Hargeisa city, experienced rapid urbanization. Local entrepreneurs financed building projects, which made the city a place of interest for many Somalians. A substantial number of Somalians from Somaliland area and Somalia moved to Hargeisa. As a result, there were about 80,000 Internally Displaced Persons (IDPs) in Hargeisa who were in need of housing (Barry 2006). In the aftermath of this movement, informal settlements were built in urban zones to host the newcomers. This led to internal conflicts between current residents and returning IDPs, which contributed to an increase in homicide and disputes between people (Barry 2006; Barry and Bruyas, 2007; International Cities of Peace 2014).

Figure 1.3. The Kood Buur municipal buildings were bombed and the land records destroyed (Barry 2006)

The above situation was further complicated by the provision of housing through private means. While this may be indicative of economic wellbeing and growth from a land tenure and housing perspective, it is problematic because these developments do not follow accepted formal procedures (Ministry of National Planning and Development 2011). In such cases, informal occupation takes place prior to dispute resolution, while the bureaucratic norm would be to start with dispute resolution, which complicates stakeholder negotiation processes. This research focuses primarily on the land disputes found between individuals, clans, and sub-clans living in the Somaliland area.

The above illustrative cases show that in conflict and post-conflict situations, land tenure information plays a crucial role in tenure conflict resolution, reconstruction processes, and the overall establishment of order. In ongoing conflict and post-conflict situations, land tenure is not necessarily secured with official documentation (*e.g.* a title). These documents need to be combined with further evidence to support tenure claims. Conventional LTISs are inadequate in such situations as most are designed to capture formal land relationships and to produce pre-designed structural forms of land documents only. For example, a title document has strict guidelines and cannot be easily changed. On the other hand, innovative LTISs, such as Social Tenure Domain Model (STDM) and Talking Titler System (TTS), capture and consider complex land relationships, in addition to registering unofficial information that can be recognized in customary law. However, these systems are unable to infer hidden relationships from the relationships that are captured. Thus, this study proposes an adaptive and descriptive LTIS database as a strategic land tool that is integrated with data mining and social network analysis techniques to infer hidden tenure relationships and investigate social matrices to support land tenure security in conflict and post-conflict situations. As well, a critical feature of the LTIS database is that it supports further development for data mining and social network analysis techniques.

1.3 Research Objectives

The study was aimed at an interdisciplinary audience. The overarching research objective was to contribute to design theory for land tenure information systems. More specifically, this research aims to illustrate the applicability of certain components of an Information Systems Design Theory framework for developing a land tenure information system that can be used in conflict and post-conflict situations. There are social and technological dimensions to this type of theory (Gregor and Jones 2007). The focus is on the technological design component of design theory with a speculative hypothesis relating to the implementation process, which provides context for the design. The hypothesis is that the application of an Information Systems Design Theory framework may provide better focus on LTIS's functionalities in conflict and post-conflict situations. Under enabling conditions (see section 6.3.1), this may lead to improved tenure security.

This research shows that it is possible to adapt the Information Systems Design Theory framework to improve the functionalities of a LTIS for conflict and post-conflict situations. In addition, the application of graph network theory to design a LTIS database that can be applied to conflict and post-conflict situations has been shown to improve the flexibility of capturing and describing tenure information and handling complex tenure relationships through modelling tenure relationships as a set of triples (nodes and unidirectional links).

1.3.1 Primary Objective

The primary objective of this research was to design and develop a schema-less graph network LTIS database prototype supported with data mining and social network analysis techniques that can be applied to conflict and post-conflict situations to improve land tenure security. This prototype was tested using open source software.

1.3.2 Specific Objectives

In order to achieve the primary objective, the study's specific objectives are the following:

a) Identify the characteristics of conflict and post-conflict situations that impact tenure security.

b) Determine the appropriate database program that can be used to develop a schema-less TTN database that supports data mining and social network analysis techniques.

c) Develop a functional TTN database prototype that supports data mining and social network analysis techniques automatically using the TTN database methodology.

d) Test the functionality of the TTN database prototype including the automatic support of data mining and social network analysis techniques using two simulated tenure scenarios, one for conflict situations, and one for post-conflict situations.

1.4 Research Questions

The following questions were asked in order to develop the theoretical context of the problem:

1. What are the operational definitions of land administration and land tenure that are in harmony with the objectives of the thesis?

2. What descriptions and characteristics of conflict and post-conflict situations influence tenure security?

3. What are the benefits of applying data mining and social network analysis to land tenure information from conflict and post-conflict situations?

4. What are the available LTIS designs that are used in unstable situations, specifically for conflict and post-conflict situations? And what are the characteristics and limitations of these systems?

In order to establish a problem context for LTIS in conflict situations, the following questions were asked:

5. What is the hypothesis that guides the proposed TTN database to support land tenure security and stabilize an unstable situation?
6. What is the most appropriate database system to use to develop and address the needs of a TTN database in conflict and post conflict situations?
7. Which database design offers a solution that is best suited for conflict and post-conflict situations? And how can it be achieved?
8. How can data mining and social network analysis techniques be integrated with the proposed database design in order to make the design more effective?

1.5 Research Methodology

During this study, the following activities were carried out in order to achieve the primary objective of the research. To address questions 1 and 2, the author examined published academic papers and textbooks that discussed different LTIS theories in conflict and post-conflict situations. This included studying and analysing academic papers and documents published by the UN-Habitat, UN-FAO, GLTN, IFAD, Oxfam, ILC, Land Matrix, the Huairou commission, and the World Bank. Furthermore, the author studied academic papers, textbooks, newspaper articles, and documents such as deeds and survey plans to gain a general background on unstable land tenure situations. Then the author identified, defined, and discussed land tenure and land administration in conflict and post-conflict situations. To address question 3, the author described and discussed one recent application of data mining and social network analysis techniques in land tenure information conducted by Barry and Asiedu, 2014. To address question 4, different land administration models such as Social Tenure Domain Model (STDM) and the Talking Titler

System (TTS) were analysed. To address question 5, the author developed a hypothesis called the Conflict and Post-Conflict Land Tenure Ladder (CPCLTL) to guide the proposed TTN. To address questions 6, 7, and 8, the author studied the causes of land conflict, and identified the users' needs, all of which contributed to designing the optimal LTIS database. Different database systems were then described and compared based on the research objectives in order to find the appropriate database system to develop the TTN database. The Triple Store database system—a NoSQL database system—was used, as well as, the Resource Description Framework (RDF) for modelling data in binary relations. Resource Description Framework Schema (RDFS) and Web Ontology Language (OWL) were used to add semantics to the RDF data model by providing a vocabulary of terms that can be used in RDF statements. Triple Store is supportive of web-based database design, where it is mainly used for semantic web database design. The semantic web is defined as a web of data (W3C 2013; Ontotext 2014).

1.6 Data

Two real-world simulated land tenure scenarios, one for the Gaza Strip in Palestine as an ongoing conflict situation, and one for the Somaliland region as a post-conflict situation, were used for the purpose of testing the TTN database prototype. However, simulated land tenure scenarios biased on these cases were used because the author could not access these sites. Simulations of tenure scenarios are sufficiently reliable because:

- The author's lived experience in an extended family house in the Gaza Strip.
- The author's supervisor's experience in Somaliland (Barry 2006).

In detailing the two simulated land tenure scenarios, the author focused on land tenure related aspects of the conflict. This means that within the data (see Appendices A and B), there exists an inherent bias towards land tenure issues. The method used for generating the simulated two land tenure scenarios is as follows:

1. Identify the problem situation.
2. Determine the key elements of the problem situation.
3. Determine and understand the interrelationships among the different elements of the problem situation.
4. Describe the problem situation.
5. Generate the simulated problem situation.

Appendices A and B describe the simulated tenure scenarios for the two cases, the limitations of the data, the relevance of the data, and the biases in the data, in more detail.

1.7 Significance

A review of relevant literature identified a knowledge gap in the design and development of LTIS in conflict and post-conflict situations. First, the development of a schema-less graph network database is new in the context of land tenure information systems for conflict and post-conflict situations. Second, data mining and social network analysis techniques are a relatively new development in LTISs. A database with built in data mining and social network analysis techniques has not been developed before. The study addresses this gap through the design, development, and testing of a schema-less graph network database system, the TTN database, that is able to capture and describe tenure information in conflict and post-conflict situations, and supports automatic data mining and social network analysis techniques.

A prior study illustrated that hidden relationships in land transactions and claims can be revealed by applying data mining and social network analysis techniques (Asiedu, 2014). Asiedu (2014) used NetDriller, a data mining and social network analysis software, on tenure data exported from TTS. The data needed to be refined prior to exportation, and attributes that were not useful were eliminated. In addition to refinement, the process of preparing data for NetDriller was cumbersome. To avoid having to prepare, export, and import data from one system to another, data mining and social network analysis techniques were integrated as tools in the author's database design to improve data processing efficiency.

The TTN database may help land administrators determine factors that may impact formal processes (*e.g.* land use plan development). In restitution cases, the TTN database may be helpful in capturing and describing tenure information in a more comprehensive manner to provide a better understanding of tenure practices on the ground. Through data mining and social network analysis techniques, the database can facilitate a better understanding of claims (*e.g.* inheritance claims) which are complex and convoluted. The database can illustrate relationships between different family members, clans/sub-clans, and property transactions by showing the different levels of relationships between family members to family members, family to family, family to clan, and clan/sub-clan to clan. Furthermore, the database can play an instrumental role in highlighting individuals who may have an influential role in dispute resolution, such as specific elders or family members. This is important for stakeholders who are involved in the purposive improvement of conflict and post-conflict situations because it assists them in focusing on the significant actors and relationships. This kind of focus ensures that the persons who are likely to have an impact or influence on the problematic aspects of the improvement processes on the ground are identified, reducing the likelihood of resistance and new contestations to such processes.

In addition, the TTN database may aid the development of appropriate policies because it helps to highlight land tenure relationships on the ground that impact formal land administration practices. Policies are often ineffective because of their neglect of on the ground practices. The assumption underlying these policies suggest that on the ground practices can be replaced by the formal way of doing things (the top down approach). By highlighting the importance of these practices as captured by the TTN database's relationship matrix, the system may better inform policies on the specific practices that are key to the effective improvement of land administration in conflict and post conflict situations. This ensures that policy makers in their efforts do not overlook these aspects.

The TTN database enlarges the area of knowledge of designing and developing a LTIS database for conflict and post-conflict situations through the application of graph network database system and the integration of data mining and social network analysis techniques within the TTN database design. The study shows that it is possible to design and develop a system that may be suitable for capturing and describing tenure relationships in conflict and post-conflict situations.

1.8 Scope and Limitations

This section illustrates the limitations of this research. The research limitations were classified into two types: theoretical limitations and technical limitations. The following describes the limitations of each type.

1.8.1 Theoretical limitations:

Land tenure disputes in conflict and post-conflict situations are complex and this challenged the design theory of the research. Certain components were not chosen for the purposes of this research. However, their inclusion may potentially help create an even better design. Moreover, this design theory outlines a particular way of approaching design and has potentially limited software development. The author is aware that developing a complete design to capture and describe land tenure disputes in unstable situations is almost impossible because land tenure conflicts are complex. A solution for an unstable and complex situation requires not only an adaptive system development approach but also new land reform programs, policies, and effective land administration. This study approaches land tenure from a technical perspective using a new design theory. Although this design theory has not been applied in the context of land information systems design, it was useful for developing a land information system design for conflict and post-conflict situations.

1.8.2 Technical limitations

Ideally, the developed database design should be tested against real-world land dispute scenarios in conflict and post-conflict situations. Unfortunately, the author was unable to visit the field due to the political unrest in the Middle East (see section 1.6). This made it difficult, if not almost impossible, to plan and make field excursions to the regions being studied. Therefore, the datasets used in this research are simulated and not real. The developed design was tested with two real-world simulated scenarios for conflict and post-conflict situations.

Within the time frame available for this research, the author was not able to design a Graphical User Interface (GUI) for the TTN database design. It needs to have a GUI in order to be applied in real life conflict and post-conflict situations, as described in future work in section 6.4.

Finally, there is a methodological bias in the experimental work of this research due to the fact that the TTN database developer simulated the two land tenure scenarios used for testing the TTN database prototype. The author developed the database based on the literature review. Following the development of the TTN database, the author simulated data for Palestine and Somaliland (see section 1.6). Then, the scenarios were entered into the initial design. Further refinement was necessary to capture the tenure information that was not accounted for in the initial design. Through iterative adjustments, the database was modified to capture tenure information that was not initially accounted for in the scenarios. Further refinement of the TTN database design is expected due to the unforeseen tenure scenarios that can take place in conflict and post-conflict situations. Refining the TTN data base design is not complex due to the schema-less model of the TTN database. Further testing is necessary to evaluate the performance of the TTN database in conflict and post-conflict situations. The limitations of the TTN database design and test for this research is described in section 5.4.4.

1.9 Chapter Summary

In sum, this thesis is about designing a flexible and adaptive schema-less graph network LTIS database that can be applied to conflict and post-conflict situations. The proposed database system is named the Talking Titler Network (TTN) database. Chapter one described the research proposal of this study. The research proposal consists of an introduction, problem statements, research significance, research objectives, research questions, research methodology, data, the scope of limitations, and the contribution to knowledge. The introduction provided a brief overview of the thesis topic. The problem statements defined the current problems related to land tenure in conflict situations. The significance of research section explained why this research is important for land tenure security purposes. The objectives of this research were divided into two parts: primary and specific objectives. The specific objectives are prerequisites for accomplishing the primary goal. The research questions are key questions of the research that should be answered in order to achieve the primary and specific research objectives. The research methodology section described sets of methods and activities were used to address the research questions in order to achieve the primary research objective. The data section described the two data sets that were obtained and used for the duration of this research to develop and examine the TTN database. The scope and limitations illustrated the restrictions that the author faced during the period of this research. Lastly, the contribution to knowledge section described the contributions of this research to overall Land Tenure Information knowledge by proposing a new database design theory to secure land tenure in conflict and post-conflict situations. The new database design theory was reflected through designing an adaptive and flexible schema-less TTN database integrated with data mining and social network analysis techniques to secure land tenure within conflict and post-conflict situations.

1.10 Organisation of Thesis

This thesis consists of five remaining chapters which are organized in the following order: Information Technology Tools for Tenure Administration in Conflict and Post-Conflict Situations; Design Framework and Database Systems for LTIS; Database Development Methodology; TTN Database Prototype Test; and Conclusion and Future Work. Chapter two addresses research questions 1, and 2. To answer these questions, it identifies and describes the characteristics of land tenure in conflict and post-conflict situations. Also, it provides a literature review of work done by different researchers in the field of LTIS. Chapter three addresses research questions 3, 4, and 5. In consideration of the primary research objective, it evaluates different database systems and determined the most suitable design for the proposed database. Chapter four describes the methodology used to achieve the primary research objective. Chapter five discusses, argues, and evaluates the results of the experimental test of the TTN database prototype. Finally, chapter six concludes the whole thesis and describes its contribution to knowledge, and provides recommendations for future work based on the TTN database limitations.

Chapter Two: Information Technology Tools for Tenure Administration in Conflict and Post-Conflict Situations

2.1. Introduction

This chapter represents the first part of the literature review. The second part of literature review is presented in chapter three. This chapter covers operational definitions of terminologies used in this research, and reviews the literature on land tenure and land tenure information systems in ongoing conflict and post-conflict situations. The objectives of the chapter are to lay out and situate the concepts of land administration and land tenure definitions, describe the characteristics of land tenure in conflict and post-conflict situations, and discuss two available LTIS software solutions for conflict and post-conflict situations. To achieve these objectives, the discussions in this chapter are divided into five main sections:

- The first section (section 2.2) presents the definitions of the land administration and land tenure terminologies, explains what land tenure means and how it is used in this study, and finally describes different types of land tenure.
- The second section (section 2.3) describes land tenure characteristics in conflict and post-conflict situations.
- The third section (section 2.4) analyses and illustrates the data mining and social network analysis techniques used in LTIS.
- The fourth section (section 2.5) reviews the available LTIS that are for unstable situations. Special attention is given to the Social Tenure Domain Model (STDM) and the Talking Titler System (TTS). Also, this section analyses, discusses, and critiques both the STDM and TTS software.
- The fifth section (section 2.6) concludes with a discussion on how the works reviewed relate to this thesis and the overall relevance of this chapter to the thesis.

2.2. Definitions of terms

In this section an attempt is made to come up with operational definitions of land administration and land tenure that are appropriate for this research project. As opposed to a scientific definition, an operational definition is “a fact or concept in terms of ‘operations’ such as controlled observation or experimentation performed by the researcher” (Barry 1999, p. xviii). In the context of this research, operational definitions are the most suitable descriptions used to describe the observable characteristics of relevant terms and concepts in the development of the TTN database design.

There are various definitions and interpretations of the land tenure and land administration concepts. Definitions of these two terms that suitably capture how they are understood and applied are presented below.

2.2.1 Land administration

In the literature discourse, *land administration* was defined differently by researchers. Dale and McLaughlin (1999 p.163) define *land administration* as “the processes of regulating land and property development and the use and conservation of land, the gathering of revenues from the land through sales, leasing and taxation, and the resolving of conflicts concerning the ownership and use of land.” The Dale and McLaughlin definition is based on a functional perspective of land administration. In their approach, they reduce land administration to four specific functions: land tenure, land use, land value, and land development (Dale and McLaughlin 1999). This, however, does not wholly capture the systemic and emergent nature of land administration. For example, on land tenure, they argue that land administration should provide clear, accurate, complete, and concise tenure information to support land management. This assumes a stable systematic context through which all the necessary tenure data can be sourced so as to provide the relevant tenure information. However, it does not comprehensively capture that which cannot be translated into data (*e.g.* emotions) and the complex family relationships that exist in many societies. This is especially so in land tenure in conflict and post-conflict situations, where land tenure is embedded within the social cultural, economic, and physical context. Therefore, the definition of land administration by Dale and McLaughlin is not adequate for the purposes of this research.

Barry (1999) depicts land administration as a conceptual system consisting of operational subsystems that give rise to land policies explicitly or implicit defined. Each subsystem has a specific purpose, and serves various functions (Barry 1999). These subsystems are integrated in a way that reflects land administration within their specific areas. Barry's characterization of land administration introduces land tenure, fiscal, economic, information management, and other subsystems, described in figure 2.1, as a set of tools that work together to reflect land administration. Moreover, these tools do not involve strategic planning or policy development. Land administration is depicted as a tool that follows regulations and rules laid out by policy makers. Land tenure is a subsystem of land administration that reflects tenure relationships in specific situations, which is the focus for this study. With regards to Barry's (1999) perspective, land administration should be viewed as a holistic system that encapsulates not only the land administration function, but also supports other functions, such as urban service provision. For example, the land tenure subsystem may provide security of tenure through registration of land interests. This is important for accessing other services. For example, a tenant has to provide proof of ownership or residency document in order to access utilities from governmental organizations. This shows the importance of having a holistic view on matters regarding land administration. Thus, Barry's (1999) definition is in harmony with the thesis' objectives because Barry's holistic view of land administration is similar to the holistic view of land relations in complex situations presented here. Figure 2.1 illustrates land administration according to Barry's definition. This research focuses on the land tenure system (see figure 2.1), which is explained in more depth and detail in the next subsection. In conflict and post-conflict situations, the uncertainty of land tenure security and its information is high. Land administrators deal with numerous types of land tenure problems (*e.g.* refugees, returning refugees, and internally displaced persons (IDPs)) in order to promote stability in the unstable social and political conditions.

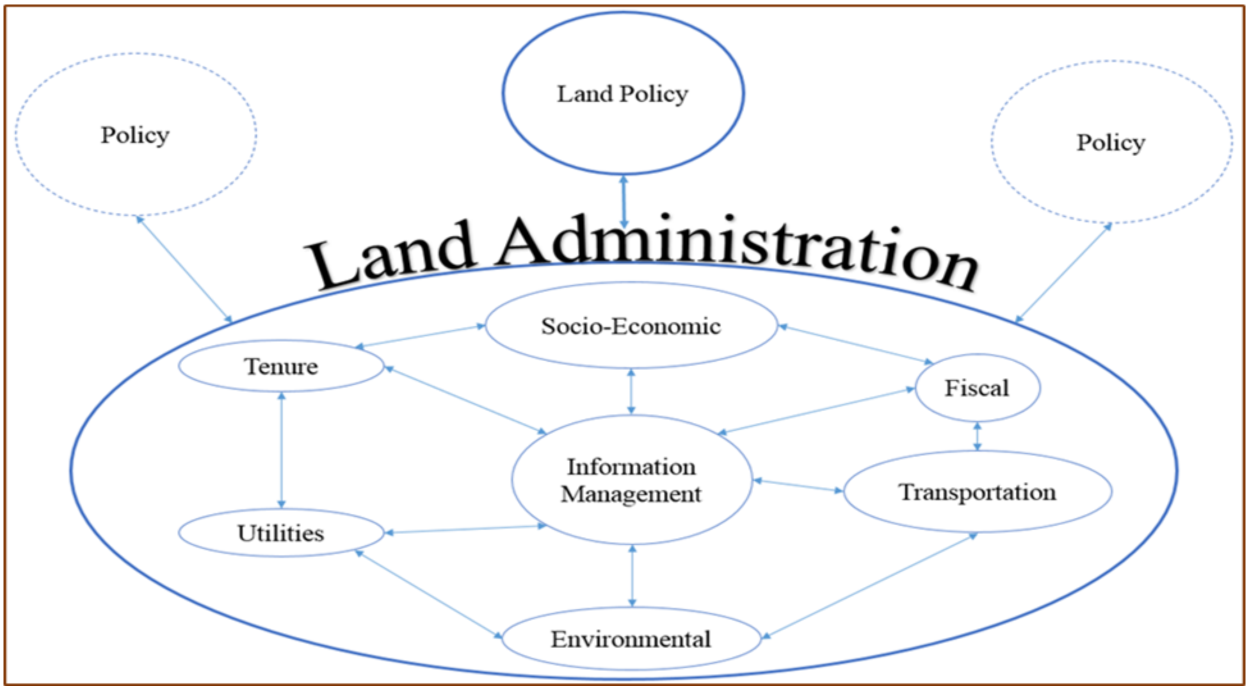

Figure 2.1. Land Administration (Barry 1999)

2.2.2 Land tenure

There is no universal definition of land tenure. What are commonly used are operational definitions of land tenure. Barry (1999 p. xvii) defines land tenure as "A system incorporating the way in which land is defined and held. It comprises a matrix of social, political, physical, and legal relationships that support and negate the holding and use of land by individuals and groups of people." On the other hand, FAO (2002 p.7) defines land tenure as "the relationships, whether legally or customarily defined, among people, as individuals or groups, with respect to land." In 2001, Van der Molen added to FAO's definition, stating that land tenure is "the mode in which rights to land are held based on statutory law, common law, and customary traditions." Land tenure consists of two fundamental concepts: "land', which represents natural resources; and "tenure" which refers to the matrix of social relations to land objects (ECA 2004). With regard to complex situations, Barry's definition is more comprehensive than the others, as it illustrates land tenure as a combination of interconnected aspects, including tenants, land, social and political issues, etc.

The interaction of these aspects is what defines the structure of society. Because Barry's definition describes land tenure as far more complex than the simple relationship between people and land, his definition is more applicable to the framework of this thesis. Barry's definition takes into consideration varying factors, such as contemporary political and social situations, that can affect tenure relationships. These factors are relevant to this study because of the highly dynamic nature of land tenure in conflict and post-conflict situations. This is due to their typically unstable political and social conditions and the imbalances of power. The following subsections discuss two different types of land tenure, private and public land tenure, in detail. These two types are explored because this research deals with local level land disputes, which primarily involve private and customary lands.

2.2.2.1 Private land tenure

Private land tenure is when the rights of a parcel of land are granted exclusively to a private party, which can consist of an individual, a family, a married couple, a group of people, or a corporate body. The ownership of this tenure permits full discretion to make a decision over his or her parcel of land within the law (*e.g.* selling, barter, developing, and disposal). These rights are assigned to the owner in the 'Land Title' documents (FAO 2002; Muhsen and Barry 2008; TMG 2015).

2.2.2.2 Customary land tenure

This type of tenure is governed under customary laws defined by the ethnic groups. These groups will have their own objectives in occupying, using, and/or alienating a parcel of land which may not be recognized by state authorities. In other words, this type of tenure that maps social structure is based on people's cultures, religion(s), rituals, and habits. Customary land tenure is still used around the world, especially within indigenous societies (FAO 2002; Barry n.d.; Takane 2007).

2.3. Land tenure in conflict and post-conflict situations

This section aims primarily to describe the characteristics of conflict and post-conflict situations in terms of land tenure. The author developed a spectrum (figure 2.2) to describe land tenure in different types of situations, where each situation is influenced by its political and social conditions. In the research context, political conditions refer to policies, regulations, and laws relevant to government. Social conditions refer to social behavior, culture, rituals, and religious influences. Descriptions of how political and social conditions influence tenure security and relationships help to describe the characteristics of land tenure in conflict and post-conflict situations. These characteristics help to specify the desirable features of the TTN database (see chapter three, section 3.4) in order to support tenure security in conflict and post-conflict situations.

Official ownership documents.	Official ownership documents and some traditional stories recited orally.	Official ownership documents, legitimacy, paper disputed, traditional stories recited orally, social change characteristics.	Official ownership documents, legitimacy, paper disputed, traditional stories recited orally, social change characteristics, multifaceted problems, internal and external conflicts, etc.
Stable	**Semi-stable**	**Unstable Complex**	**Unstable extremely complex**

Situation Bar

Figure 2.2. Characteristics of land tenure in different types of political and social conditions

Land tenure characteristics are influenced by varying political and social conditions. Conflict and post-conflict situations can range in stability which can impact the characteristics of tenure security and relationships in a region. Conflict and post-conflict situations vary in complexity. As illustrated in figure 2.2, the range begins at stable situations, moves toward semi-stable, then unstable and complex, and ends at the unstable extremely complex situations. Each situation describes different circumstances of land tenure. In stable situations, political and social conditions are stable. The conventional registration systems, such as land registration, are adequate enough to secure land. The registered land objects are secured as the official ownership documents are enough to prove the ownership of a property (Barry n.d.; Groupecho Canada Inc. 2015). Most land disputes can be resolved in court. Once political and social conditions start to deteriorate, stable situations begin to develop into semi-stable situations.

In semi-stable situations, land claims should be supported with official ownership documents and some unstructured data, which include traditional stories recited orally and unofficial documents, to represent proof of ownership for a piece of land (Bruce et al. 2006). Many contradictory documents and stories can be collected from different individuals (*e.g.* tenants, families, witnesses, and neighbors) about a land dispute. These documents and stories may be represented by rituals and/or symbols that were legitimately used to convey tenure transactions (Barry n.d).

If situations deteriorate to the point where official documentation is inadequate and political and social conditions are unstable, as well as dynamic, then these situations can be described as unstable complex. A post-conflict situation is an example of unstable complex situations, where it refers to the period of time that began after the end of a conflict in a given region (Nkurunziza 2008). In this situation, many tenure claims arise and should be addressed in order to avoid any potential violence (Unruh 2016). However, addressing these claims is not an easy task due to many unexplained underlying issues, political or civil unrest being examples. Also, the official ownership documents are not enough to secure property, as people often resort to their oral stories as evidence of ownership (Muhsen and Barry 2008; Unruh 2016).

Lastly, unstable and extremely complex situations will have dynamic political and social conditions, and are characterized by a large migration of individuals fleeing from ongoing conflict and political/civil unrest. In ongoing conflict situations, land tenure systems are subject to illegal exploitation and destruction for political and social gains (Muhsen and Barry 2008; Unruh 2016). Also, civilians flee their places of origin and become refugees, or IDPs, in other countries. They assume that they will soon return to their places of origin. Some refugees, or IDPs, believe that carrying tenure documents could put them at risk during their unsafe trip. In this case, land objects are at risk of being grabbed and illegally occupied due to the ongoing conflict and the existing gap between legality and legitimacy (Barry and Bruyas 2007). However, presently, the majority of refugees try to engage in online internet applications, such as social media, to follow up on the situations in their home country and monitor their tenure. They also use these applications to communicate with people who are still living in the conflict situation in order to communicate information (*e.g.* pictures and videos) related to their tenure objects (Unruh 2016). When the conflict has officially ceased within a region, the post-conflict situation begins, and refugees try to return back to their places of origin. Thus, large numbers of land tenure claims and disputes arise. People provide a variety of evidence and information that support their claim (Muhsen and Barry 2008; Unruh 2016). This information includes pictures, audio and video recordings, water and electricity bills, verbal stories from witnesses, and any available tenure documents like contracts or deeds (Unruh 2016).

In conflict and post-conflict situations, stakeholders play an essential role in supporting tenure security by capturing tenure information and dealing with tenure claims. A flexible and adaptive LTIS database that is able to capture and describe tenure information is one of the strategic tools stakeholders need to support tenure security and deal with tenure claims in conflict and post-conflict situation (Unruh 2016).

To conclude, conflict and post-conflict situations are characterized by land disputes, social and political unrest, the frequent destruction of land records, and a high number of land claims supported by different types of informal documents and unstructured data. These tenure disputes and claims present significant dilemmas for tenure security and improving these situations is challenging, possibly due to a large number of fraudulent documents, lack of evidence, and complex nature of tenure relationships. To support tenure security in complex situations, stakeholders are in need of an adaptive database system that supports data mining and social network analysis and is able to capture and describe tenure information in a flexible way (Barry and Asiedu 2014; Unruh 2016). The data mining and social network analysis techniques and its implications for LTIS databases are further discussed below.

2.4. Data Mining and Social Network Analysis for LTIS

This section describes data mining and social network analysis techniques and the importance of applying these techniques to land tenure information for conflict and post-conflict situations. In addition, the section illustrates one of the recent implementations of these techniques in land tenure information.

Data mining and social network analysis techniques are very useful when applied to land tenure information for conflict and post-conflict situations (Asiedu 2014). These techniques aid in constructing, modelling, and analysing the social networks that characterise conflict and post-conflict regions. Also, they are able to reveal hidden tenure relationships and extract tenure patterns from the captured tenure information (Asiedu 2014; Barry and Asiedu 2014). Data mining is the process of extracting implicit knowledge or pattern(s) from explicit data. Social network analysis is a technology used to predict or discover social behavior trends in order to draw the social matrix of a society by analysing relationships among social objects (Zaki and Meira 2014, p1; Butts 2008).

In the context of this research, a rudimentary form of data mining was applied in a semantic database, i.e., Triple Store database (see section 3.4.1.1.1). In this context, rudimentary data mining is defined as extracting hidden relationships in the data through connections (*e.g.* grandfather – daughter) which are not explicitly defined in the data entry process. In conflict and post-conflict situations tenure data tends to be unstructured, complex, inconsistent, rapidly changing, and difficult to understand (Muhsen and Barry 2008; Unruh 2016). Drawing on Kabir et al., (2014), these data features make it difficult to understand the data for land tenure administration purposes. To improve these situations, the Triple Store database enables the support of database mining through the semantic database modeled by the Resource Description Framework (RDF) ontology (see section 3.4.1.1.1.1). The Triple Store ontology languages, Resource Description Framework Schema (RDFS) and Web Ontology Language (OWL) combined with the RDF enable the database to make sense of the entered conflict or post-conflict tenure data through interlinking all possible items of data, classifying data, and then disambiguating the data. This enables the rudimentary mining process to reveal or extract hidden tenure information by navigating all possible indirect and direct links or paths among tenure data items (Kabir et al., 2014).

In 2014, Barry and Asiedu adopted data mining and social network analysis techniques to track changing tenure relationships, visualize social relationship network, and highlight the power structures of the network. The techniques were applied to draw different social and physical tenure relationships in studying a customary tenure system in Ghana. The dataset was exported from the TTS database and reformatted to fit the NetDriller software. The dataset used involved people's names, land objects, methods of acquiring land (*e.g.* inheritance, purchase, rent, etc.), media (*e.g.* deeds, scanned documents, pictures, videos, etc.), and family relationships. The Net Driller settings were adjusted to mine and analyse the following relationships in the relational database: Person-Person, Person-Media, Person-Land, and Land-Media. Also, NetDriller was used to model the social networks implicit in the data. The dataset was manipulated as a multi-mode network through the use of graph theory terminology. Each mode describes a specific type of relationship. Mode 1 describes relationships among one type of object (*e.g.* Person-Person). Mode 2 describes relationships among two different types of objects (*e.g.* Person-Media, Person-Land, or Land-Media). After applying the social network analysis technique, different social patterns and tenure relationships were discovered that had not been considered before. Furthermore, the use of social network analysis visualization simplified the complexity of tenure relationships among objects.

The extracted patterns were then used to organize existing social structures, changes that would help in securing tenures and promoting societal stability. Overall, the results of the experimental work demonstrated that adopting social data mining and network analysis techniques to analyse tenure information of unstable situations aids in securing tenures and alleviating the uncertainty of unstable societies (Barry and Asiedu 2014). The experimental work of Barry and Asiedu proved the importance of data mining and social network analysis techniques applied in unstable situations. The techniques extracted important social and tenure patterns that can be considered to secure tenure and mitigate land disputes (Barry and Asiedu 2014).

In this context, it appears that data mining and social network analysis techniques have been used by Barry and Asiedu only recently. However, these techniques have been used by other researchers for different contexts, and were not applied to conflict and post-conflict situations. To date, Barry and Asiedu's experimental work best illustrates the application of data mining and social network analysis techniques in the context of post-conflict situations. In the next section, the author reviewed the different Land Tenure Information Systems available for conflict and post-conflict situations.

2.5. Existing LTIS for conflict and post-conflict situations

This section describes two available LTIS developed for unstable situations - the Social Tenure Domain Model (STDM) and the Talking Titler System (TTS). These systems were chosen because the author has access to both of them, and they are well-known available LTIS that can be applied in unstable situations. The author attempted to test the Open Title system (ESRI 2008), but was not able to obtain access for it from its developers. The following subsections describe and analyse the conceptual software design of the two available systems, STDM and TTS in the context of conflict and post-conflict situations.

2.5.1 Social Tenure Domain Model (STDM)

STDM is a pro-poor land registration and recordation system that is most accessible to those living within low-ranking economic communities (UN-Habitat et al 2012; GLTN and UN-Habitat 2016). The STDM software aims to capture land relationships and secure land interests in low income contexts (UN-Habitat 2012; UN-Habitat et al 2012; UN-Habitat/GLTN 2014). The main goal of STDM development is to support pro-poor land administration by filling the gap between formally registered land and unregistered land (Lemmen 2010). The first draft version was released in 2007 under the supervision of Christiaan Lemmen (ITC 2015; Muhsen and Barry 2008). In 2014, UN-Habitat released STDM version 1.0 in the market, which is the most recent version of STDM at the time of writing this research (Kahiu 2015). The database system used for designing the STDM database is PostgreSQL, which is a relational database system (Kahiu 2015). The STDM conceptual model is based on the Land Administration Domain Model (LADM). LADM is a land tenure information and cadastral system that became an ISO standard in 2008 (ISO19152) (Lemmen 2009; UITERMARK et al 2010; Gitau et al 2014). The LADM conceptual model is a top-down approach (Asiedu 2014). This means that the software may be developed deductively without applicable field studies. They used a problem solving approach to address the issue of supporting tenure security, and they started by defining and articulating the issue that they wanted to resolve (Lemmen 2009; Gitau et al 2014). The system was then designed to solve this pre-defined problem without first studying tenure practices taking place on ground. The design of their system took into consideration the desired ISO standard. This means that though the design is necessitated by the need to support tenure security in unstable situations, their system is biased to ISO standard at the expense of the functional requirements of conflict and post-conflict situations.

Practically, the emphasis in the STDM design is capturing and describing land-people relationships, and this is clear in the conceptual model (Gitau et al 2014). Figure 2.3 depicts the conceptual model of the STDM software. As shown in figure 2.3, the Party objects represent tenants that consist of either an individual or a group of people. The Social Tenure Relationship objects depict numerous rights that tenants possess over a land object. For example, person A has the right to cross over land object L, whereas person B has ownership of land object L. A Spatial Unit object describes the different characteristics of the land object such as area, borders, land type, natural resources, and spatial location. The Supporting Documents object pertains to different types of evidence that describe the titles of a tenant over a parcel of land; these documents are used as evidence to support tenants' claim over a land object. Supporting documents can be survey records, survey plans and diagrams, legal documents created in the survey, cadastral information system plans, audio/sound records, and written documents.

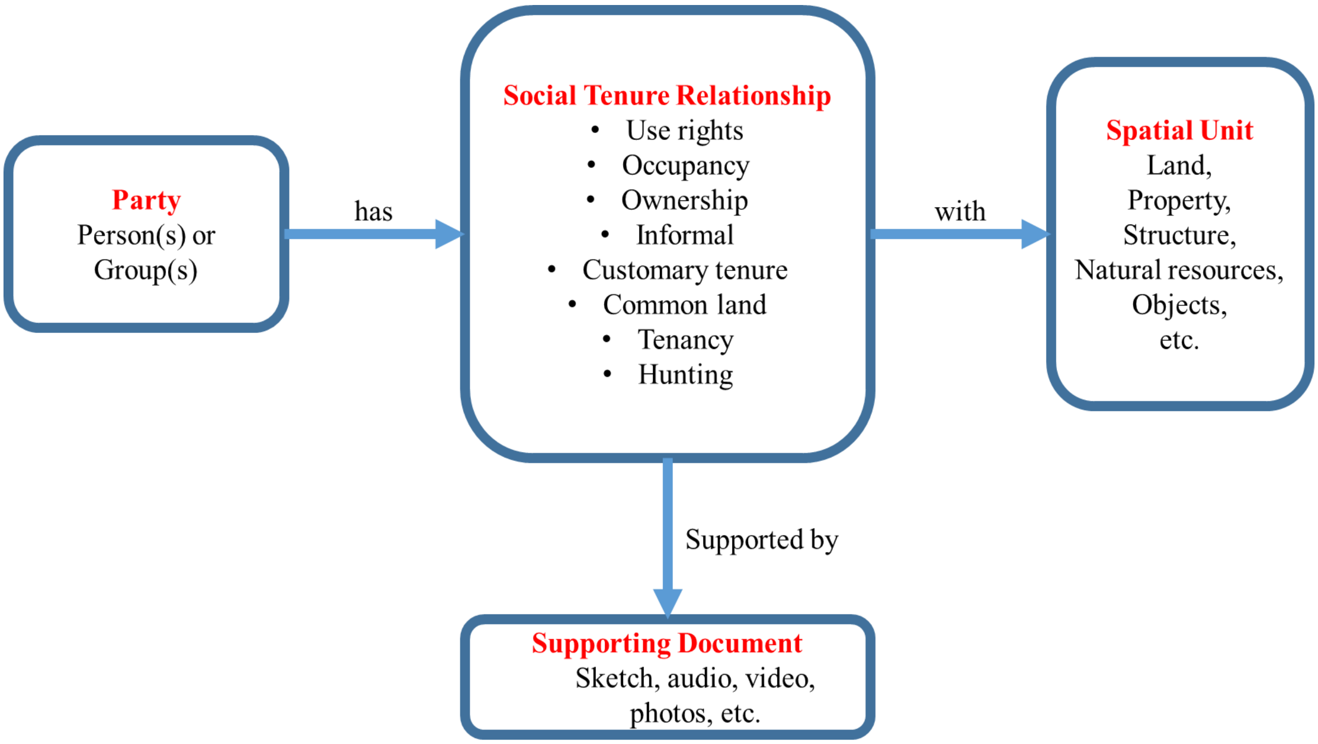

Figure 2.3. STDM conceptual model (CheeHai and Antonio 2013)

The following subsection analyses, discusses, and critiques STDM in terms of conflict and post-conflict situations. The conceptual model of the STDM is critiqued in the contexts of this study, and the analysis is not based on experimental tests. As shown by Flyvbjerg (2006), it is possible to critique the conceptual model that informs an experimental work. As the STDM design is informed by a conceptual model, one can critique the design based on its conceptual model. Though the results may not be compelling due to the fact that the author did not experimentally apply the STDM software to the study contexts, the analysis points to significant shortcoming of the software in these contexts. Further tests will need to be undertaken.

2.5.1.1 Analysis and discussion

The STDM is actually a special case of the LADM in the ISO standard. As mentioned earlier, the STDM core design is greatly influenced by the LADM design, as their fundamental objects are the same but with different terminology. It is stated in ISO/ TC211 N2385 that, "the LADM contains the functionality for the STDM, but under incorrect terminology" (ISO/TC211 N2385, 2008, p. 22). This brings up questions of whether STDM is an adaptive LTIS and effectively 'fit for purpose' in conflict and post-conflict situations, and whether STDM is a convenient and advantageous design overall. Practically, the STDM was designed as a land registration system to serve slum areas and informal settlements rather than a system for capturing and describing complex tenure relationships and claims in conflict and post-conflict situations. At best, STDM can be described as a functional approach to tenure relationships, developed within the framework of ISO standard (Lemmen 2010). In order to meet ISO standards, STDM needed to follow certain criteria. Based on an analysis of the conceptual model, in following these criteria STDM's flexibility in capturing tenure information may be limited. In order to capture tenure information in dynamic situations, a system needs to be flexible; however, drawing on Asiedu (2014), STDM may omit some significant aspects of land tenure, such as disputes, when capturing tenure data on the ground.

If one takes the above description at face value, the STDM model is biased towards a top-down approach that may omit significant tenure relationships that exist on the ground within complex situations (Asiedu 2014). Generally, the top-down approach does not begin by studying and analyzing the relationships as they exist in complex situations. It designs solutions to deal with these situations before comprehensively analyzing them (Muhsen 2008). On the other hand, the bottom-up approach starts with studying and analyzing the relationships as they exist on the ground. Based on the acquired information and knowledge, the solution for handling problems on the ground can be designed (Muhsen 2008). Therefore, it may not be as efficient to apply STDM within conflict and post-conflict situations without first assessing the requirements of those situations; especially when these situations are characterized by rapidly changing social conditions and plenty of complexity (Asiedu 2014; Muhsen 2008).

The immediate needs of people in conflict and post-conflict situations are security and peaceful coexistence (Unruh 2016). First and foremost, these needs can be achieved through tenure conflict resolutions, where land is one of the major causes of the conflict (Muhsen 2008; Muhsen and Barry 2008). Therefore, these situations require an adaptive and flexible LTIS that stands apart from the top-down approach land registration system, as it often may not address the issues of complex situations (Muhsen and Barry 2008). Based on Lemmen (2010), STDM is a top-down land registration and recordation system for pro-poor communities below the poverty line. The system helps those people who are living within low-ranking economic communities to register their properties and acquire land titles to ensure ownership security (UN-Habitat et al 2012; GLTN and UN-Habitat 2016). Thus, STDM may prove adequate to secure tenure in poor communities since it is developed mainly to describe people-land relationships (Lemmen 2010). In conflict and post-conflict situations, land disputes are dynamic and often multifaceted and can change according to varying political and social influences (UN 2012 and EU; Mwesigye and Matsumoto 2013). Also, tenure relationships are more complex than people-land relationships.

To conclude, conflict and post-conflict situations are complex and in need of a LTIS that emphasizes tenure conflict resolution and complex tenure relationships, not registration. The system should be able to capture and describe complex land tenure relationships effectively in order to handle land disputes and claims on the ground. In addition, the system should support data mining and social network analysis techniques to support decision making in tenure security (see section 2.4).

However, the author did not use the STDM design as a basis to develop the TTN database design model for the following reasons, which are based on an analysis of the STDM conceptual design and literature review:

- STDM works under the ISO standard (ISO/TC211 N2385, 2008, p. 22; Lemmen 2010). ISO is applicable in many places across the world, however the contexts of certain areas render the application of ISO standard problematic. Basing an LTIS on ISO standard for these contexts may make the system inadequate, as in the case for dynamic situations, such as conflict and post-conflict situations. STDM follows an ISO standard that was developed using a top-down approach, generating a rigid database system design that is not designed for a specific context (UN-Habitat et al 2012; GLTN and UN-Habitat 2016). In conflict and post-conflict situations, tenure relationships are dynamic and often difficult to define at the outset. These situations require a system design based on the bottom-up design approach, which begins by assessing tenure requirements on the ground before system development to support tenure security. As a result, the system that is developed would not be based on a pre-defined database schema.
- Based on the STDM conceptual model, STDM is mainly used to describe land-people relationship. However, in conflict and post-conflict situations, tenure relationships are not limited to land-people relationship. They also include different types of tenure relationships such as: people-people, document-document, people-document, land-document, and land-land. These tenure relationships are not explicitly illustrated in the STDM conceptual design model.
- Drawing on the STDM user manual (2015), STDM does not support data mining and social network analysis techniques automatically. This limitation is due to the database system

used to develop the STDM database, PostgreSQL database, is a relational database system. The PostgreSQL database cannot reveal hidden tenure relationships, extract tenure pattern, and investigate the social matrix of a region. PostgreSQL warehouse (database) should be integrated with an external third party application that supports data mining and social network analysis techniques (Bartolini 2009).

2.5.2 Talking Titler System (TTS)

The author has worked on developing the TTS software on the Windows platform as part of his research program. Thus, the author knows the software intimately.

Talking Titler System is a land tenure information system that was designed to secure tenure within post-conflict and other forms of complex situations (Barry and Khan 2005). The TTS design is still under development. The concept behind the TTS is that conventional LTISs are weak in describing tenure relationships in unstable situations and in customary societies, which may generate improper results in these situations (Barry et al 2013). The philosophy behind the TTS model is to develop a system that can mitigate land disputes between people whilst taking into consideration cultural factors and maintaining flexibility (Barry et al 2013; Muhsen and Barry 2008). Basically, TTS was designed to cope with uncertainty and allow for assembling tenure information at the ground level (Muhsen 2008). Thus, TTS utilizes a bottom-up approach design, where its flexibility allows for a simpler understanding of captured tenure relationships in uncertain situations.

TTS handles two registration types: documented agreements and oral agreements. The documented agreements include titles, deeds, survey plans, and descriptive documents. The oral (verbal) agreements include audio records and videos. Documented agreements can be entered into the TTS database tables. These tables were developed using a relational database system, the

Microsoft Access database (Muhsen 2008). The oral recorded documents (*e.g.* taped videos, recorded voice, and pictures) are stored inside "user-created" folders to be linked with the related object (*e.g.* person, land object, etc.) inside the database at a later time. The conceptual relational database design model of the TTS consists of four main entities: person, land object, media, and reference instrument. These entities are all connected together directly in order to describe different relationships among them. Therefore, TTS takes more of network approach to tenure relationships (Muhsen and Barry 2008). Figure 2.4 depicts the conceptual model of the TTS. As shown in the figure, the person class represents parties which can be a group of people, a company, a family, or an individual (UN-Habitat 2012; Muhsen and Barry 2008). The land object class describes house(s), trees, field(s), parcel, and etc. The media class describes video(s), taped-audio(s), photograph(s), survey plan(s), and paper-based document(s) (Muhsen and Barry 2008). The reference instrument class serves as a link among the three classes (person, media, and land object). The critical feature of the TTS is that each class can be connected to itself and directly connected to the others. For example, two members from the same class can be connected together through a relationship such as siblings, deputy, family member, etc. In addition, a member from the person class can be linked to any member of the other classes directly through suitable relationships (Barry et al 2013).

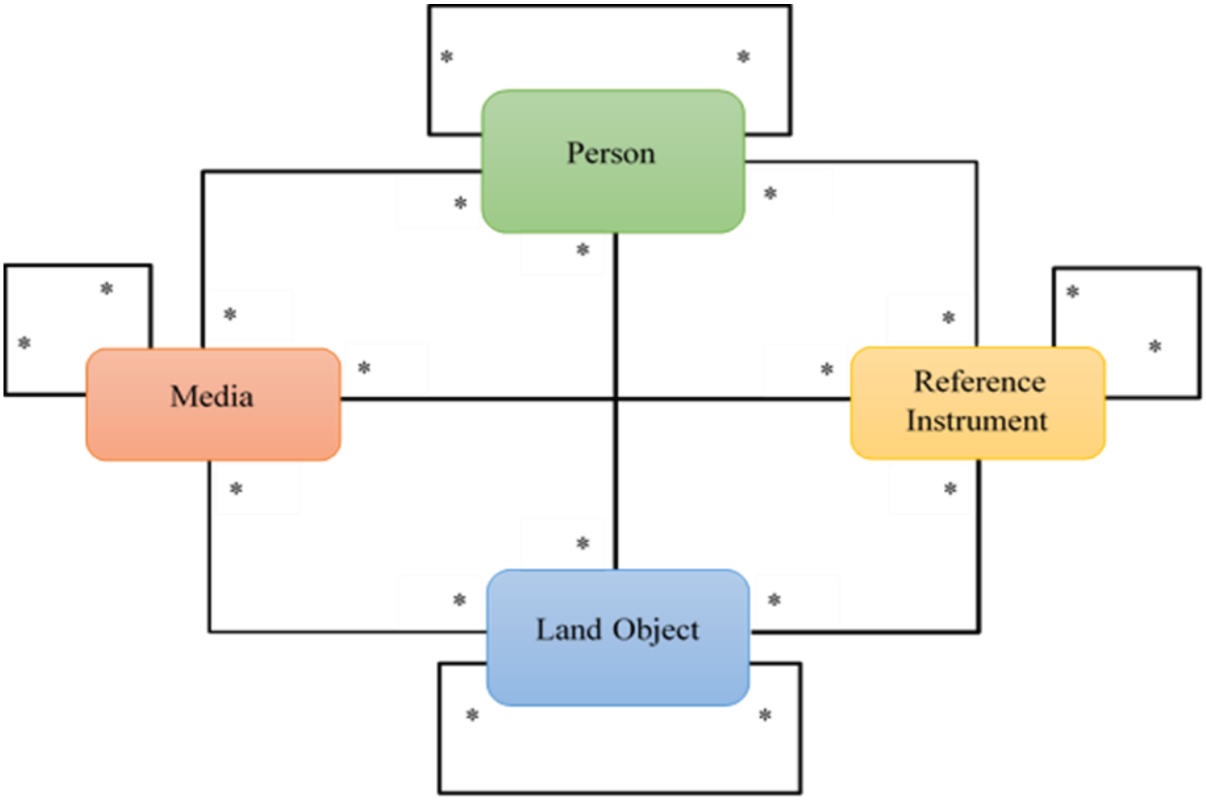

Figure 2.4. Talking Titler Software conceptual model (Muhsen 2008)

Drawing on the author's experience in developing the TTS software, the following subsection analysis, discusses, and critiques TTS in terms of the research context.

2.5.2.1 Analysis and discussion

As mentioned recently, TTS is a bottom-up land tenure information system for complex and post-conflict situations (Muhsen and Barry 2008). This can be attributed to the system's consideration of different characteristics of complex situations in its design model. The bottom-up Talking Titler design model considered different complex social and tenure relationships on the ground. TTS describes land tenure information through the four entities (person, land object, media, and reference instrument) and the established relationships among them (see figure 2.4); which is different than the STDM design model (see figure 2.3). The TTS model is better suited to complex situations than STDM due to its capability to capture and describe different types of complex tenure relationships. The technical design of the TTS database focuses on flexibility at the expense of robustness: flexibility being that both data and relationships can be captured and described interchangeably (Muhsen 2008). In addition, the TTS configurations can be adjusted from the Look Up table that is located in the Configuration tab in the TTS toolbar to meet certain necessities (*e.g.* editing values from the droplist of an attribute). Technically, all the binary relationships between the TTS entities are of the many-to-many type. However, the many-to-many relationship type is not recommended by database developers because the database can become convoluted (Song et al. 2001; Muhsen and Barry 2008). This convolution challenges tenure data analysis; thus, the need to integrate social network analysis techniques. Muhsen, the TTS developer, said that (Muhsen 2009, p.97):

> [T]hese classes are connected via many-to-many relationships. This allows a great deal of flexibility in the manner that data are collected and related. This loose structure allows data to be collected and related in many different ways and is suited to uncertain situations where user-requirements are ill-defined and data must be collected rapidly.

The author is partially in agreement with Muhsen because the many-to-many relationship type allows a flexibility in capturing and describing complex relationships, but it may misrepresent specific tenure relationships on the ground. For example, in an asymmetric relationship type (*e.g.* a relationship between a child and a father) and a hierarchical relationship type (Agricola 2014; Dullea et al., 2003). These types of tenure relationship are unidirectional and should be described from one direction only (Horridge 2011; Agricola 2014; Dullea et al., 2003). For example, Alex is the father of Tom; or land object *A* is part of land object *B*. The many-to-many relationship describes Alex is the father of Tom; and Tom is the father of Alex. It, also, it describes land object *A* as part of land object *B*; and land object *B* as part of land object *A*. Therefore, the way that the

TTS is configured may misrepresent asymmetric relationships that are meant to be described comprehensively, especially in inheritance disputes where tenure relationships need to be described clearly for stakeholders. To overcome this limitation, the TTN database captures and describes tenure relationships using a unidirectional one-to-one link.

To conclude, conflict and post-conflict situations are complex and in need of an adaptive and flexible LTIS that is capable of capturing and describing tenure information effectively. Due to the complexity of tenure information and relationships, data mining and social network analysis techniques are important for consideration in order to support decision making in tenure security (see section 2.4). TTS provides flexibility in capturing and describing tenure information in complex situations, but TTS may misrepresent asymmetric tenure relationships because of the established many-to-many relationships among its classes. Also, TTS database does not support automatic data mining and social network analysis techniques. As stated in section 2.4, tenure data has to be exported to an external application (*e.g.* NetDriller software) for data mining and social network analysis purposes.

However, the author considered the concept and the philosophy behind the TTS to develop the proposed TTN database for conflict and post-conflict situations, because the TTS software is specifically for capturing and describing tenure relationships in complex situations. To avoid some of the limitations of relational database systems, the author examined different non-relational database systems in chapter three to develop TTN.

2.6. Relevance to Research

The content of this chapter contributes to achieving the overall objective of the thesis by addressing the following research questions:

1. What are the operational definitions of land administration and land tenure that are in harmony with the thesis objectives?

2. What are the descriptions and the characteristics of conflict and post-conflict situations that influence tenure security?

3. What are the benefits of applying data mining and social network analysis to land tenure information from conflict and post-conflict situations?

4. What are the available LTIS designs that are used in unstable situations, specifically for conflict and post-conflict situations? And what are the characteristics and limitations of these systems?

Addressing these questions enabled the author to situate his work within existing knowledge about land tenure information and land tenure databases. Questions 1 and 2 were answered through the examination and analysis of published academic papers and textbooks that discuss different LTIS theories in conflict and post-conflict situations. The author identified and defined land tenure and land administration in conflict and post-conflict situations. Then the author analysed and discussed land tenure in conflict and post-conflict situations to determine the desirable features of the TTN database, which will be described in chapter three.

To answer research question 3, the author described and discussed one recent application of data mining and social network analysis techniques in land tenure information conducted by Barry and Asiedu, 2014. Their experimental work shows the importance of considering data mining and social network analysis techniques in conflict and post-conflict situations. Data mining and social network analysis are explained. How these techniques are applied in the thesis is presented in chapter three.

Finally, to answer research question 4, the author discussed, analysed, and critiqued two available LTISs, STDM and TTS. The author illustrated the limitations of these two systems in conflict and post-conflict situations, specifically with regards to their inability to support data mining and social network analysis techniques. STDM has a top down approach that meets the ISO standards. Subsequently, STDM may omit some significant aspects of land tenure such as disputes when capturing data. TTS is limited when it comes to describing asymmetric tenure relationships.

In this chapter, points of departure in terms of definitions and context are clearly established. The author identified gaps in existing knowledge, specifically with regards to the limited but growing body of research on data mining and social networking techniques in land tenure information systems. Moreover, limitations in available systems were considered and will be accounted for in the design of the TTN database.

2.7. Conclusion

This chapter described and discussed land administration and land tenure in conflict and post-conflict situations in section 2.2. In conflict and post-conflict situations, land tenure is one of the crucial issues that stakeholders should focus on in order to manage land disputes and promote stability, particularly in areas where land is one of the main causes of conflict. The author further described different types of land tenure that are relevant to the research in sections 2.2.2.1-2. It is important to consider different types of land, specifically private and customary lands, as this research is focused on developing a database to assist in resolving private and customary tenure disputes in conflict and post-conflict situations. In these situations, land disputes are dynamic and complex due to interlocking tenure relationships.

The characteristics of land tenure relationships in conflict and post conflict were described in detail in section 2.3. The complexity of land disputes and tenure relationships make it difficult for stakeholders to understand tenure disputes, however data mining and social network analysis techniques can assist in improving this understanding. Thus, section 2.4 introduced data mining and social network analysis techniques and illustrated their application in the research completed by Barry and Asiedu. In 2014, Barry and Asiedu applied data mining and social network analysis techniques on land tenure information in the post-conflict situation is Ghana. The results of their experimental work showed social patterns and tenure relationships that had not been considered before. Therefore, their results emphasized the importance of considering data mining and social network analysis techniques in complex situations. Afterwards, section 2.5 discussed the Social Tenure Domain Model (STDM) and the Talking Titler System (TTS) as LTIS for unstable situations. In this section the author described the philosophies behind their designs, and outlined the limitations of these two systems in the context of conflict and post-conflict situations. This chapter contributed to the achievement of the main objective of this thesis in two ways. Firstly, a literature review was conducted to determine suitable definitions and to identify gaps in existing knowledge. Secondly, this chapter illustrated the author’s contribution to improving available systems for land tenure disputes. Chapter three describes the second part of the literature review and illustrates the theoretical framework of the TTN database.

Chapter Three: Design Framework and Database Systems for LTIS

3.1 Introduction

This chapter represents the second part of the literature review. The objectives of this chapter are as follows:

- Describe and explain the Conflict and Post-Conflict Land Tenure Ladder (CPCLTL) hypothesis to illustrate how the author's Talking Titler Network (TTN) database, as a LTIS database, may help to support tenure security and promote stability in unstable complex situations, specifically conflict and post-conflict situations, under the enabling conditions (*e.g.* acceptance of the system by stakeholders). Use the hypothesis as a guide for the design of the TTN database.

- Describe and apply a theoretical design framework to focus on components that would be essential for the design of the TTN database.

- Investigate Database Systems literature, aiming primarily to identify the database system that is most suitable for developing the TTN database for conflict and post-conflict situations.

This chapter begins by describing a hypothesis called the CPCLTL, which serves as a conceptual tool to guide the Talking Titler Network (TTN) database.

The CPCLTL describes the gap between *de jure* and *de facto* in conflict and post-conflict situations, and illustrates the TTN database's role in supporting tenure security by capturing and describing tenure practices on the ground in conflict and post-conflict situations. Following a discussion of the CPCLTL, the chapter introduces Gregor and Jones' (2007) information system design theory which served as the basis for the author's design theory. The discussion in section 3.4 highlights the features that the TTN database should contain and analyses different non-relational database systems, specifically a graph database system (Triple Store) that can be used to develop a TTN database. The characteristics and features of the Triple Store Database are elaborated upon in further detail in sections 3.4.1.1 and 3.4.1.1.1. The methodology for developing TTN design is discussed in further detail in chapter four.

The topics covered in this chapter include: (i) conflict and post-conflict land tenure ladder; (ii) theoretical design framework; (iii) Database systems and LTIS design; (iv) relevance to research; and (vii) conclusions.

3.2 Conflict and post-conflict land tenure ladder

Drawing on the literature and the author's experience of living in Palestine, the author developed the CPCLTL to conceptualize land tenure problems in conflict and post-conflict situations, inform the design of the TTN database, and illustrate the role that the TTN database plays in serving as a tool to assist in stabilization. In the context of this research, the CPCLTL examines the *de facto* and *de jure* land tenure relationships in conflict and post-conflict situations. The CPCLTL describes how these situations can be improved incrementally.

De jure and *de facto* are critical concepts when discussing land tenure in conflict and post-conflict situations. In land tenure, *de jure* reflects statute laws as they are written and enforced by the government, whereas *de facto* reflects the actual social practices that take place on the ground that constitute the tenure system as it really occurs and customary laws that are influenced by society (Lee et al. 2009; FAO 2002). The relationship between these two concepts is that both reflect the state of land tenure security in different situations (Lee et al. 2009; FAO 2002).

For simplicity, the spectrum of unstable to stable land tenure security situations (see figure 2.2, chapter two) was separated into the following four stages: stable, semi-stable, unstable complex (*e.g.* a post-conflict situation), and unstable extremely complex situation (*e.g.* an ongoing conflict situation). The CPCLTL is used to conceptualize land tenure problems in unstable complex (*e.g.* a post-conflict situation), and unstable extremely complex situations (*e.g.* ongoing conflict situation). To move up the ladder and increase stability, the social structure and *de facto* rules of land tenure practices must be understood within their societal context.

The amount of overlap (size of the overlapped area) between *de facto* and *de jure* portions of the ladder is representative of overall stability of a specific region. In a stable country, such as Canada, where the relationship to property (*e.g.* land object) is well-defined in a government document, landholders are secured against threats since *de jure* and *de facto* overlap. The social practices that take place on the ground are recognized and enforced by the government or judiciary. In contrast, in an unstable jurisdiction, there may be little overlap between *de jure* and *de facto*. The social practices that take place between individuals are not necessarily recognized and enforced by the government or judiciary. Stable contexts can be assumed to have a large overlapping area, while unstable situations can be expected to have a gap or a small overlap between *de jure* and *de facto*.

In unstable political and social situations, government supported documents are often insufficient to secure tenure. This is because, as depicted in figure 3.1, the gap between *de facto* and *de jure* tenure may be wide. Unstable regions are characterised by complex and unsecure tenure situations, where land is often one of the major drivers of social conflicts (Maiese 2003). Understanding unstable situations entails a solid and comprehensive understanding of the social matrix.

With the interest of ameliorating the gap between *de jure* and *de facto*, an adaptive TTN database design is needed that is flexible enough to capture and describe the land tenure practices on the ground, and infer implicit knowledge from the captured explicit data.

All in all, the purpose of such a TTN is to provide information, such as revealing hidden relationships, which can be useful for handling land disputes through social negotiation processes that should reduce the gap between *de facto* and *de jure*. This reduction can be conceptualized as a movement along a ladder from a complex tenure situation and its accompanying tenure insecurity towards a less complex situation that has secured tenure as portrayed in figure 3.1.

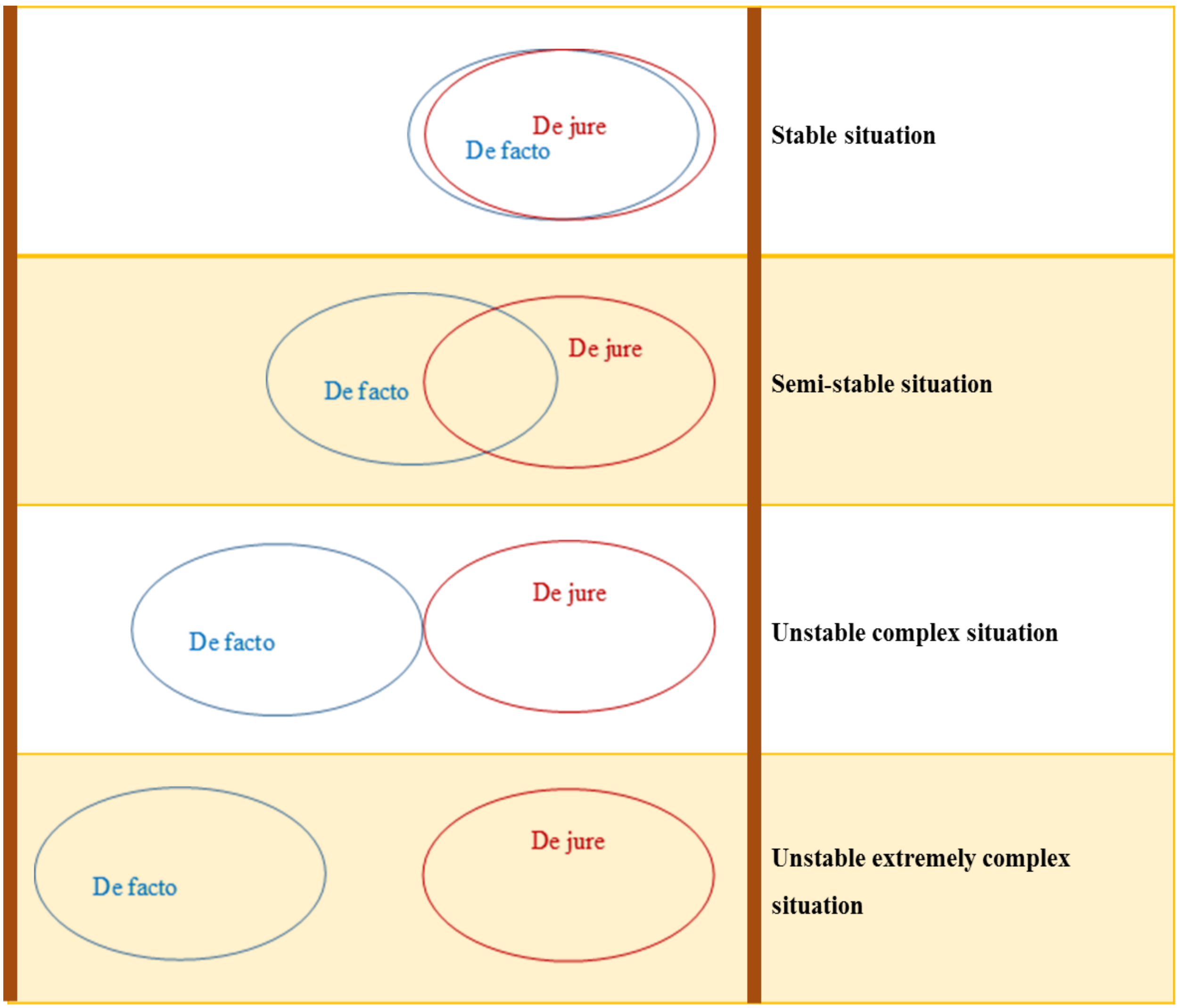

Figure 3.1. Conflict and Post-Conflict Land Tenure Ladder

The CPCLTL depicted in figure 3.1 illustrates land tenure in different situations, and shows how with each movement up the ladder, improves in stability, moving towards tenure secured by official instruments and structures under stable conditions.

The author's argument is that a flexible, adaptive, and descriptive TTN database design that is able to provide rich descriptions about a land tenure is a possible tool that can gradually lead to bridging the gap between *de jure* and *de facto* land tenure situations in conflict and post-conflict areas. In conflict and post-conflict situations, some *de facto* practices are not reflected in *de jure* practices. The system is designed to meet the needs of the bottom levels, unstable extremely complex situation and unstable complex situation of the CPCLTL. This system captures *de facto* practices in conflict and post-conflict situations (complex situations) and provides information that is important for stakeholders during social negotiation processes. To assist in resolving land tenure disputes, land law(s) should be amended to consider significant tenure practices on the ground, which in turn, mitigate land disputes and stabilize situations. The need for the system becomes irrelevant when situations become semi-stable and stable.

3.3 Theoretical design framework

The Information System design theory developed by Gregor and Jones (2007) serves as the framework for the proposed TTN database. This formal theoretical framework facilitates a rigorous critique based on a theoretical structure. Existing LTIS software solutions (*e.g.* STDM) have neglected to place the design within a theoretical framework. Thus, the scope of the situations to which they may apply has not been articulated. Failure to do this may perpetuate the problems that some land titling programs have created. For example, a land titling program was inadequate to support tenure security in Afghanistan, a post-conflict situation. The program was not developed to cater for the post-conflict situation, as it failed to take into account the impacts of the years of conflict (*e.g.* tenure patterns on the ground and social norms) (Wily 2003; Wily 2004; Gaston and

Dand 2015). Therefore, developing a LTIS system within a theoretical framework may provide better focus to LTIS's functionalities within specific contexts, conflict and post-conflict situations because the different components of the system can be described individually within a framework that links these components in a logical way. From this framework, several components are selected and applied without iterations for the design objectives. The following are the main components of the TTN database design theory framework (Gregor and Jones 2007):

1. Purpose and scope: this design component describes the aim(s) and the scope of the TTN database. This component has been covered in chapter one, section 1.3.1. To recap, the aim is to develop a database that is flexible in describing tenure relationships. The scope of this work is focused on land tenure in conflict and post-conflict situations, not the type of situations that exist, for example, Canadian cities.
2. Constructs: it describes the entities of interest in the theory (Gregor and Jones 2007). In this theory the constructs are what is relevant to the TTN database design. In the author's TTN design, these include people, land object, tenure relationships, transactions in land, evidence, and claims to land.
3. Principle of form and function: it describes "the structure, organization, and function" (Gregor and Jones 2007, p. 325) of the TTN database design. Form in the context of the TTN database describes the GUI, which depicts the appearance of the TTN database for the end user and how the user can interact with the database. On the other hand, function shows how well the TTN database addresses the problem of supporting land tenure security in conflict and post-conflict situations through a schema-less graph network database integrated with different ontology languages that support data mining and social network analysis techniques. The scope of this project is limited to the design and testing

of the functional component of the TTN database. A major part of the analysis in chapter five, sections 5.3 and 5.4, examines whether the TTN addresses the functional requirements of the system.

4. Testable propositions: it describes a hypothesis about the system in the form of "if a system or method that follows certain principles is instantiated then it will work, or it will be better in some way than other systems or methods" (Gregor and Jones 2007, p. 327). The proposition being tested by the TTN database design is described as follows: A TTN Graph Network database is very effective at capturing, describing, and mining complex tenure relationships in conflict and post-conflict situations because it supports data mining and social network analysis techniques.
5. Justificatory knowledge: it provides an explanation of why the proposed design should work (Gregor and Jones 2007). The proposed TTN database design should work because it organizes tenure information into a set of triples, where each triple is the smallest entity of the TTN graph network database. A triple consists of three components, a subject, a predicate, and an object (Ontotext 2014; Zicari 2015). By describing tenure relationships as a set of connected triples, the database is able to automatically mine tenure information through integrated data mining and social network analysis techniques; complex tenure relationships can be simplified and effectively described for stakeholders. Triples are further discussed in section 3.4.1.1.1.

In terms of the above theoretical framework, the main focus of this research project was the third component, the principle of function. This research focused on the principle of function by addressing the limitations of existing LTISs databases and advancing LTIS database development through the design and testing of the TTN database functional components.

The analysis of existing LTISs such as STDM and TTS through the above framework show the following limitations in STDM and TTS (also see chapter two, section 2.5). They:

- Do not support data mining and social network analysis techniques, as they are relational database systems.
- Are unable to investigate and build on social matrices automatically, since they are not graph network databases.
- Cannot reveal hidden social and tenure relationships, since they do not have data mining and social network analysis techniques.
- Sometimes misrepresent specific types of social and tenure relationships (*e.g.* asymmetric relationship type).

The proposed TTN database design addresses these limitations by enabling data to structure and build upon itself through the addition of new links and nodes, which capture and describe:

- Different types of social and tenure relationships, specifically asymmetric, unidirectional, relationships.
- Hereditary social tenure relationships.

In the next section, the author discusses database systems that are capable of supporting the TTN design.

3.4 Database Systems and LTIS Design

This section seeks to find the appropriate database system to suit the desired TTN design. Based on the characteristics of complex tenure systems (see chapter two, section 2.3), the desired features of the proposed TTN database design are described. As mentioned in sections 2.3 and 3.2, the major characteristics of complex land tenure situations include:

- Instability due to changes in social and political issues.

- Complicated land tenure relationships.
- Unstructured land tenure information.
- Land tenure disputes and relationships that are influenced by social behaviour in a given culture.

Therefore the desired features of the proposed TTN database are:

- Flexibility in capturing and describing land tenure information.
- The ability to support and facilitate data mining and social network analysis processes.
- The ability to permit further development without causing the database design to collapse.

For this study, database systems are classified into two types: Relational Database Systems (RDBSs) and Non-Relational Database Systems (Non-RDBSs). RDBSs organize and store data into relational tables, where these tables are connected together through logical relationships. In order to design a reliable TTN database using a RDBS, the database developer is required to pre-define different relational database models and schemas. The pre-defined schemas should capture and manipulate land tenure information and relationships. Drawing on MongDB (2016), Couchbase (2016), and Nnace et al. (2013), RDBS was eliminated from consideration because of the following points:

- RDBS is a schema-based database approach and requires a predefined database schema, which is very difficult in conflict and post-conflict cases due to the aforementioned challenges.
- RDBS organizes data in rigid database schemas. This type of database schema is not suited to capturing unstructured data and unforeseen scenarios.

The next section focuses on exploring different Non-RDBSs and in selecting the appropriate database system for the problem context.

3.4.1 Non-Relational Database Systems (Non-RDBSs)

The Non-RDBSs type was developed to overcome the limitations of RDBSs. Non-RDBSs can organize data in a schema-less way, where data can be visualized in different forms such as a network or a set of tables. In terms of LTIS, organizing data in a schema-less way and visualizing them in the form of network is important to capture and understand complex land tenure information. Caviness (2012) states that, "[w]ith a schema-less database, 90% of the time adjustments to the database become transparent and automatic." This means that the schema-less design model allows the database to be refined many times in order to be adapted within a certain condition. To this effect, the schema-less database design model is intended to support the flexibility of the TTN database to capture and describe land tenure information in conflict and post-conflict situations. The Non-RDBSs type consists of different categories, where each category contains a set of database programs. The most common categories are (Markey 2012; Pantanowitz et al. 2012; Manoj 2014):

- Document Based (Document Oriented): the fundamental concept of a document oriented database is the concept of a document. Basically, this database category stores data inside documents. Each document has a unique key-value and the document stores the data of a single object. Different documents can be connected through key-values. The Document Based database organizes data into rows and columns, but without a rigid schema or structure (Strauch 2009). MongoDB, CouchDB, and RavenDB are examples of Document Oriented database programs (Strauch 2009; Schwartzenberger 2011).

- Graph based: this category was developed based on graph theory. It consists of a set of nodes connected by links (edges). Data is stored inside nodes and links, wherein each link describes a logical relationship between two connected nodes. Each node stores information of an object. Neo4j, Triple Store, and HyperGraphDB are well-known graph based database programs (Strauch 2009; Neo4j 2014; Angles and Gutierrez 2008).
- Wide Column Store (Column Families): this category can be described as a set of columns, where it stores tables of data as sections of columns instead of rows. Wide Column Store database has a reliable schema. This database category is adequate for storing and manipulating massive amounts of data. Therefore, it is used by companies that manipulate and store millions of data sets daily such as, Google, Facebook, and Twitter. Big table, Hadoop, and Cassandra are well-known Wide Column Store database programs (Morrison 2015; mongoDB 2016).
- Key-Value Store: this database category stores data as a dictionary or big hash table. Each record of the table consists of two values: the entered data value, and a unique key associated with the value for retrieving data from the database (Seeger 2009). Amazon DynamoDB, Redis, and Memcached are Key Value Store database programs (Nayak et al., 2013; Zimanyi 2015).

The aforementioned categories vary in abilities and features. The author focused on two features: data complexity and data size. The two features were selected because the proposed database design should handle large amounts of complex land tenure information. Figure 3.2 differentiates among the database categories described above in terms of scalability and complexity. Scalability refers to data volume and the ability of the database category to manipulate large volumes of data distributed among different servers. Complexity refers to the complexity of data structure and the ability of the database category to manipulate different structures of data (couchbase 2015; mongoDB 2015).

With regards to scalability, figure 3.2 shows that the Key-Value Store category supports data scalability more than the other categories, and with regards to data complexity, the figure shows that the graph database category is more capable of manipulating high-complexity data than the other categories (Neubauer 2010; Vardanyan 2011; Amazon 2015).

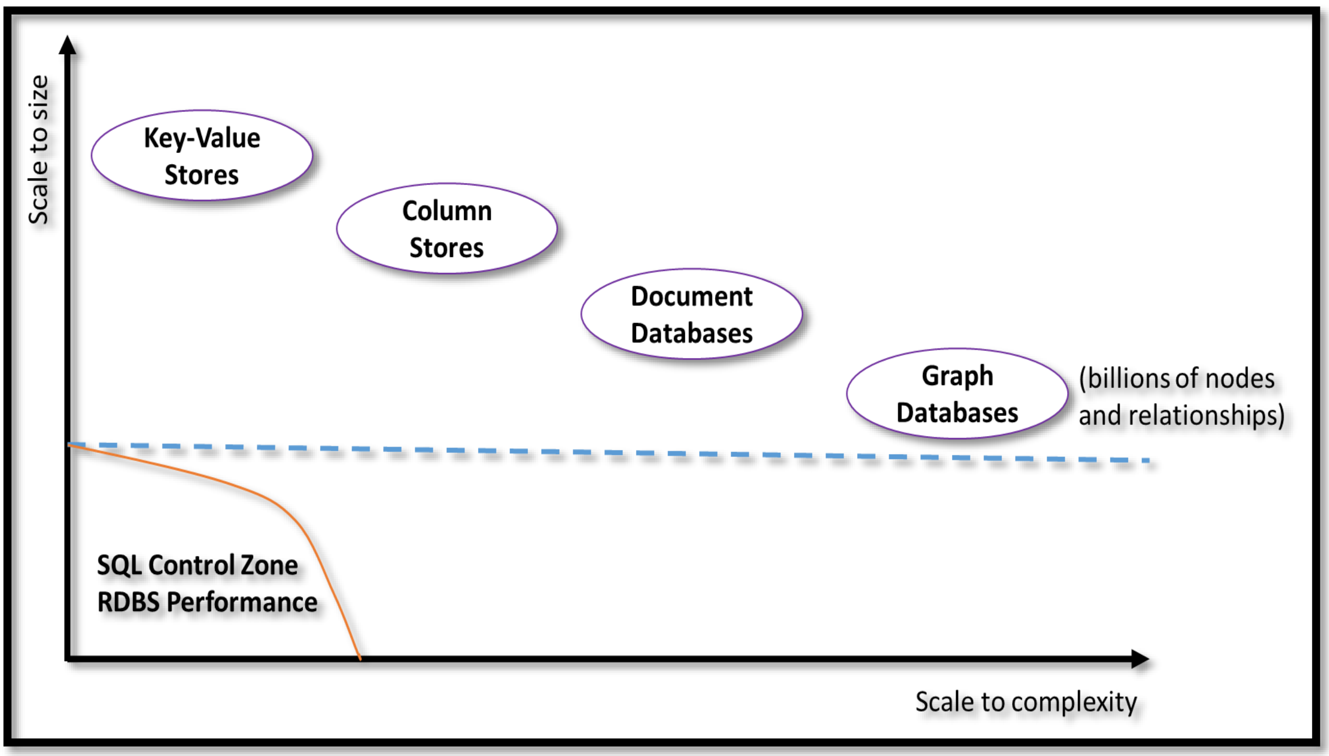

Figure 3.2. NoSQL Data Models. Source: (Neubauer 2010; Vardanyan 2011)

The Graph database category is more capable of manipulating different levels of data complexity compared to other database categories (Strauch 2009). In addition, a graph database is capable of storing billions of nodes and relationships (Zicari 2015). Considering the features required of the proposed database design and the challenges of complex situations, the graph database is the most appropriate one to use, as compared to the others. Therefore, the author focused on the graph database and discarded the other categories. The next section describes the graph database category in greater detail in order to find the most appropriate database program to use for the proposed database design.

3.4.1.1 Graph Database

Graph databases use nodes and links to store, manipulate, and visualize data. A node can represent a class type (*e.g.* clan) and a subclass of an existing class (inherited class) (*e.g.* sub-clan and family). Also, the node represents the object of an existing class (*e.g.* name of a sub-clan). Nodes are connected through links, where each link represents a logical relationship between two nodes (Robinson et al. 2015). Figure 3.3 shows a graph database (Part A) representing classes and subclasses in a hierarchical structure. It also illustrates how a relationship can be represented between two nodes in Part B. Assuming that we want to represent a relationship, such as "Sub-clan *A* owns land object *L*", the relationship between the sub-clan *A* and land object *L* can be represented using the graph database as shown in figure 3.3, part B.

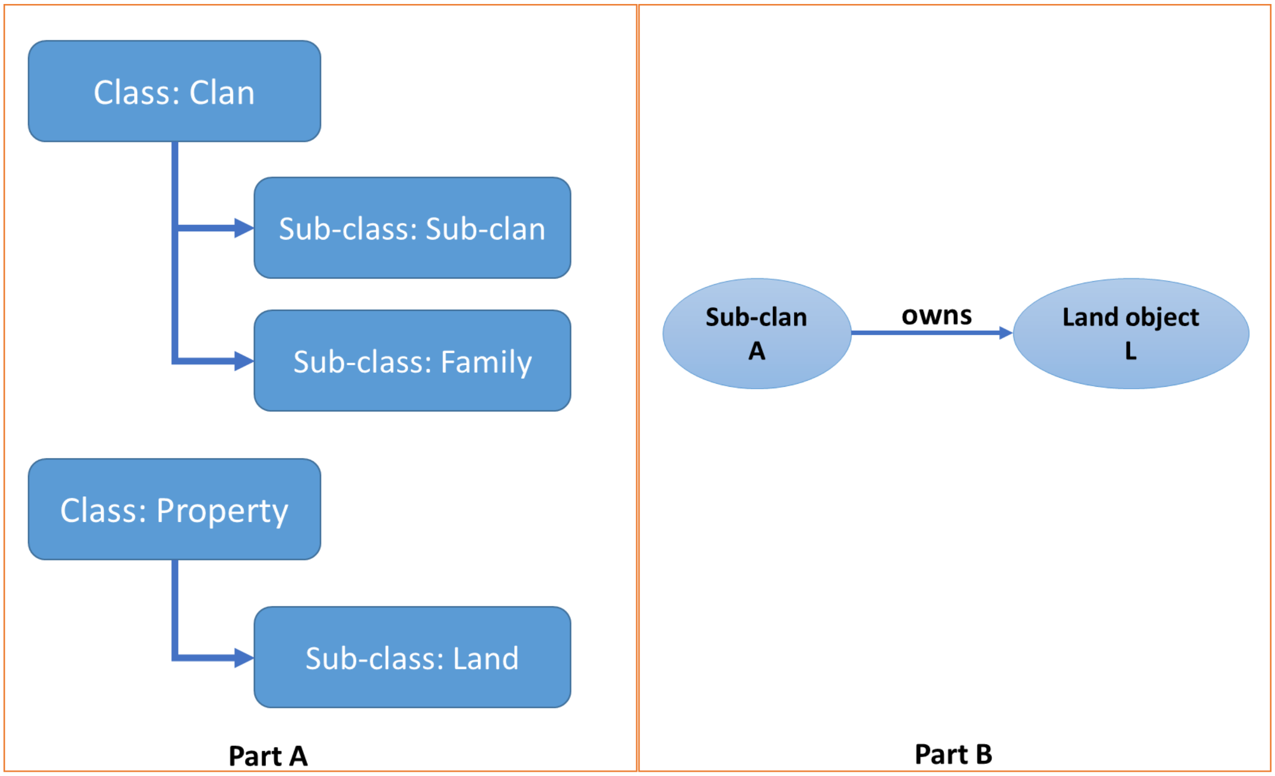

Figure 3.3. Classes and relationships in graph database

The Graph Database category consists of many graph database systems. Common Graph Database programs are described below (Robinson et al. 2015):

- HyperGraphDB:

HyperGraphDB is a graph database system and it was developed based on the BerkeleyDB database which is an open source database that supports data scalability. HyperGraphDB visualizes data as a graph network consisting of nodes and links. All the information is stored in the form of key-value pairs, where each component (node or link) in the graph is identified with a single key called "Atom." The HyperGraphDB links are directed. Each link has one or more sources and one or more destinations. This means that one link from the HyperGraphDB database can be connected with different nodes and links. Therefore, most database developers use the HyperGraphDB program to visualize complex graphs such as genetic graphs (Kobrix 2010; Iordanov n.d).

- Neo4j:

Neo4j is a graph database system that consists of nodes connected by directed links. A node describes an entity which can be a real object such as a person, land object, or etc. A link describes a logical relationship between two nodes. Each node and link consists of a set of attributes (a table) to describe a node object (Neo4j 2014). For example, to collect information about a person, a node is created to represent a person. The node contains a set of attributes used to describe a person such as: name, age, gender, and date of birth.

- Triple-Store:

Recently, Triple-Store Database has seen widespread adoption as one of the dominant forms of graph database systems. This can be attributed to its ability to handle complex data models and relationships, and portray them in a way that is easily understood by both humans and computers. Therefore, Triple Store database is used to build smart applications (Ontotext 2014; MarkLogic 2016). The database was developed based on three fundamental concepts: subject (*s*), predicate (*p*), and object (*o*). The simplest form of the database is called a Triple and is a combination of subject, predicate, and object. The subject and the object are nodes connected through a predicate. A predicate requires the source and destination nodes to be defined in order to establish a direct relationship between subject and object. The source node is the subject, and the destination node is the object (Ontotext 2014). For example, Tom owns land object “Lot01.” Tom is a subject, “Lot01” is an object, and the verb “owns” is the predicate of the triple.

The Triple Store database is able to handle different types of data structure (structured, semi-structured, and unstructured), where any piece of information can be organized as a triple. Also, the Triple Store database supports the integration of data mining and social network analysis as built-in tools in the database design (Ontotext 2014). This was identified as a desirable feature in the beginning of section 3.4.

Based on the desired features of the proposed TTN database and the challenges of complex situations, the Triple Store database is the most appropriate program to use for the design of the proposed database. The Triple Store database program stores data in a schema-less way, where all the data is organized as different statements in the form of subjects, predicates, and objects. This feature makes the database flexible in capturing any type of data regardless of its complexity. Triple Store can be used to better visualize data complexities, where data objects are distributed among predefined classes. Each class describes its data objects, which makes the captured data self-described. Moreover, the Triple Store database visualizes data as a network; and it supports different ontology languages which can be used to integrate data mining and social analysis networks techniques into the database design (Ontotext 2014; Aasman 2011). The following section describes the Triple Store database and its ontology languages in further detail.

3.4.1.1.1 Triple Store Database

The Triple Store database system is a non-relational and open source network graph database system. Triple Store does not pre-require a schema or a data relational model definition. Due to this feature, it provides higher flexibility in representing schema changes and operations (Ontotext 2014). The Triple Store database is able to capture different data structures. The Triple Store database structures data as a network of nodes and directed links. It captures input as individuals, and these inputs are nodes representing individuals of different classes.

Each class can be defined to describe different individuals. For example, we can define two classes: the human class, and the animal class. To differentiate people from elephants, and tigers, the human class is defined as organisms that have two legs, and the animal class is defined as organisms that have four legs. Based on the classes' definitions, the Triple Store database describes people as individuals of the human class, while elephants and tigers are described as individuals of the animal class. The Triple Store database relationships link individuals from the same class or different classes.

Triple Store relationships are classified into two types: object relationships, which are used to describe a relationship between two individuals from the same class or different classes; and data relationships, which are used to link an individual of a class with a data value (*e.g.* text, number, string, and date) (Bechhofer et al. 2015; Horridge 2011; Puigjaner et al. 2002).

Triple Store visualizes data (sets of triples) in three modes: a graph network; a table comprising three attributes: subject, predicate, and object; or combination of the mentioned two modes. This combination depicts a graph network with a list of statements organized inside a table to provide more details about a selected node or relationship in the network (Horridge 2011). Example 3.1 illustrates how the Triple-Store database organizes and visualizes data.

Example 3.1:

This example describes the tenure relationship between a person, Rami Dremly, and a land object, "LO120." Rami Dremly is described below:

- Rami Dremly owns LandObject01.
- Rami Dremly has the following personal information:
  - Person's ID: PA00123.
  - First name: Rami.
  - Middle Name: Fady.
  - Surname: Dremly.
  - Gender: male.

    - Age: 25.
- The following details Land Object LO120:
    - Land Object ID (Lot_ID): LO120.
    - Area: 350 m^2.
    - Land type: private.

The Triple Store database organizes data as triples, and visualizes it as a graph network, table, or both. The following tables, 3.1 and 3.2, show how the Triple Store database visualizes data in table mode:

Table 3.1. Triples corresponding to Rami's information

Subject	Predicate	Object
RamiDremly	hasID	PA00123
RamiDremly	hasFirstName	Rami
RamiDremly	hasMiddleName	Fady
RamiDremly	hasLastName	Dremly
RamiDremly	hasGender	Male
RamiDremly	hasAge	25
RamiDremly	Owns	LandObject01

Table 3.2. Triples corresponding to the land object "LO120"

Subject	Predicate	Object
LandObject01	hasLotID	LO120
LandObject01	hasAreaInM2	350
LandObject01	hasType	Private

As shown in tables 3.1 and 3.2, each row describes a triple, which is considered as a piece of information. For example, "RamiDremly owns LandObject01", "RamiDremly hasFirstName Rami," and "RamiDremly hasGender Male."

To display the captured information (example 3.1) as a graph network, the Triple Store database visualizes the database subjects and predicates as nodes; the predicates are links that connect the nodes though logical relationships. Figure 3.4 demonstrates how the Triple-Store database demonstrates example 3.1 as a graph network.

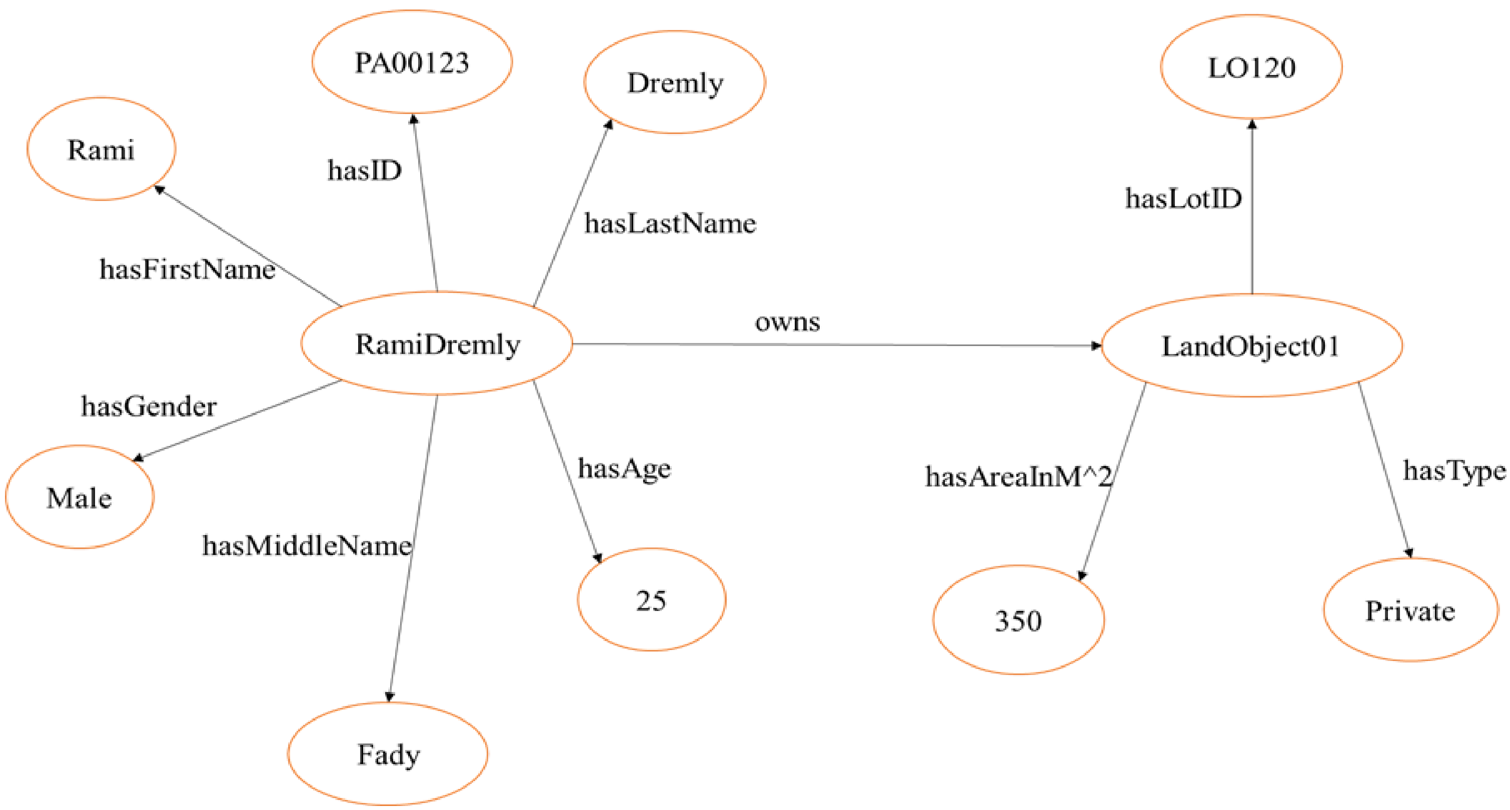

Figure 3.4. Triple Store Graph Network of example 3.1

The figure shows a set of nodes connected by directed links. The subjects and the objects are represented as nodes, where the predicates are represented as links. Each link is directed from a subject towards an object to describe a logical relationship. In the graph network, we can see that "RamiDremly owns LandObjec01", "RamiDremly hasID PA00123," and "LandObject01 hasType Private."

3.4.1.1.1.1 Triple Store models and ontology languages

The conceptual data model of the Triple Store database is a type of ontology. Resource Description Framework (RDF) is a schema free data model, and uses URI (Uniform Resource Identifier) to identify the triples' components (*s*, *p*, *o*). The Triple Store database has its own ontology languages to define and model different classes and relationships. RDF is the Triple Store data model, where it organizes data as triples (Ontotext 2014). The RDF tags that relate to data modelling constructs are illustrated as the following:

- Entity class: <rdf:subject>
- Relationship: <rdf:predicate> + <rdf:object>
- Attribute: <rdf:predicate> an attribute of </rdf:predicate>

For example:

<rdf:subject> Land Object ID 0521 </rdf:subject>

<rdf:predicate> is owned by </rdf:predicate>

<rdf:object> Alex </rdf:object>

The subject (source) and the object (destination) of a relationship are specified based on two concepts: domain, and range. The domain describes the subject classes, while the range describes the object classes of a relationship. The subjects are individuals of the classes that are defined as domain, while the objects are individuals of the range classes (Curé and Blin 2014; Ontotext 2014). For example, assume Alex is an individual of a class named *TenantPerson*, and "Lot01" is an individual of a class named *LandObject*. A relationship named "Owns" was defined to describe that tenant *A* owns land object *L*. In this case, the *TenantPerson* class is the domain and the *LandObject* class is the range of the "Owns" relationship. Therefore, Alex is the subject and "Lot01" is the object of the "Owns" relationship. Figure 3.5 describes this example.

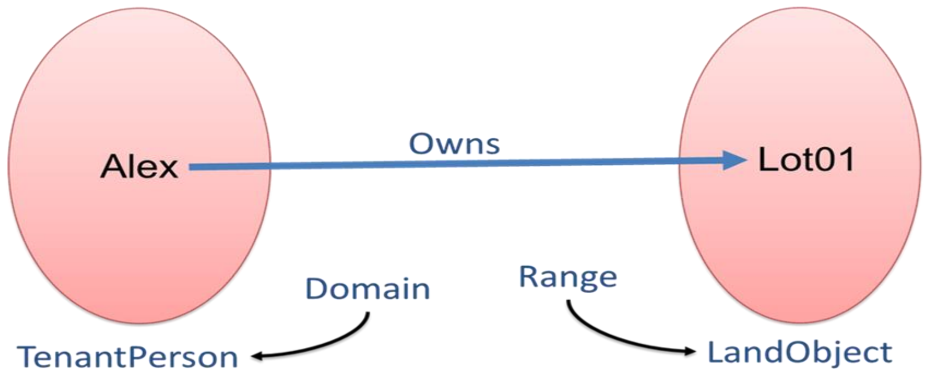

Figure 3.5. A relationship domain and range

However, a drawback of the RDF model is that it may model a relationship in a manner which may have multiple interpretations. A descriptive generalization of a relationship might lead to some confusion. For example, the word "bank" can be used to describe either "a commercial bank" or "a river bank." RDF's description is limited to differentiating between the two different meanings of the word "bank." Therefore, Resource Description Framework Schema (RDFS) and Web Ontology Language (OWL), ontology languages are used to formulate the topological features and the constraints of the RDF triples (Rodriguez et al. 2013; Ontotext 2014).

RDFS is an extension of RDF. It is used to develop semantic Web and Web 3.0 applications. RDFS extends definitions for the Triple Store classes and relationships. Also, RDFS is used to define constraints on the defined classes and relationships. For example, assume we used RDF to define two classes: *Person* and *Plant*. The *Person* class captures and describes persons, and the *Plant* class captures and describes plants. Individuals of the *Person* class should not be individuals of the *Plant* class. To apply this constraint, we use RDFS to define it. Furthermore, RDFS provides a kind of universal translation between alien languages. Developers use RDFS to create their own data models and define tags of: classes, subclasses, ranges, domains, and resources. The data model of RDFS constructs are defined as the following (Ontotext 2014; Cambridge Semantics 2015; Cambridge Semantics 2016):

- Entity class: <rdfs:class>
- Attribute <rdfs:domain>
- Relationship: <rdfs:range>
- Instance: <rdfs:type>

For example, assume that “Sold By” is a relationship that describes the land object that is subject to sale. *LandObject* and *Tenant* are two classes defined to describe different land lots and tenants, respectively. The domain of the “Sold By” relationship is the *LandObject* class and the range is the *Tenant* class. This relationship can be defined as the following:

```
<rdfs:property rdf:about=“http://www.semanticweb.org/#Sold By”>
<rdfs:domain>LandObject</rdfs:domain>
<rdfs:range>Tenant</rdfs:range>
</rdfs:property>
```

However, RDFS is limited to describing semantic constructs and defining some constraints on relationships and classes. Therefore, OWL was developed to address RDFS limitations. OWL was defined recently in this section.

OWL ontology has the same RDFS concept, but it is more capable of describing classes, subclasses, and relationships in further detail. Therefore, it is used to define semantic constructs and provides additional descriptions and constraints on the defined relationships and classes (Cambridge Semantics 2015; Horridge 2011). The difference between RDFS and OWL ontologies is described in the following example.

Example 3.2:

Assume that we need to create a class called *Person* to add different persons. The *Person* class can be created and defined by RDFS. To differentiate among individuals added in the class in terms of their social roles (*e.g.* father, sibling, and uncle), we use OWL ontology. For example, person *A* is the father of person *B*, person *B* is the son of person *A* and the father of person *D*.

OWL is developed based on RDF and RDFS. It is constructed from Extensible Markup Language (XML) tags. OWL's syntax can be interpreted directly by computers (Hay 2006). The OWL tags that relate to data modelling constructs are illustrated as the following:

- Entity Class: <owl:class rdf: id="…">
- Attribute: <owl:datatypeProperty rdf:id="…">
- Relationship: <owl:objectProperty rdf:ID="…">

For example, assume that the "Sold By" relationship is to be established between individuals from *LandObject*, as a domain class, and *Tenant*, as a range class. In this relationship, each land lot can be only be sold by one seller (tenant) only. The following is the model of the "Sold By" relationship using the OWL ontology language:

```
<owl:Class rdf:ID="LandObject">
<owl:Class rdf:ID="Tenant">
<owl:DatatypeProperty rdf:ID="Sold By">
<rdf:Type rdf:resource="owl:#FunctionalProperty"/>
<rdfs:domain: rdf:resource="#LandObject"/>
<rdfs:domain: rdf:resource="#Tenant"/>
</owl:DatatypeProperty>
```

As shown above, the *LandObject* class is the domain of the relationship, while the *Tenant* class is the range. This means that the source node of the “Sold By” relationship must be an individual from the *LandObject* class, while the destination node must be an individual from the *Tenant* class. The “Sold By” relationship has a “FunctionalProperty” property type. This means that each individual from the *LandObject* class can be linked with only one individual from the *Tenant* class. The next section describes the different types of Triple Store relationship and the characteristics of each type in detail.

3.4.1.1.1.2 Triple Store relationship properties

This section describes different types of Triple Store relationships and the associated characteristic(s) with each type. Triple Store relationships are divided into two types: object property, and data property relationship. Each relationship type has its own characteristic(s). The following two sections describe the types of Triple Store relationships:

1. **Object property relationship:**

The object property relationship is used only to describe a relationship between two individuals from the same class or different classes. This relationship type has seven characteristics (properties) that can be used to define a relationship and its constraints. The following are the characteristics of the object property relationship (Bechhofer et al. 2015; Horridge 2011):

- *Functional*: it restricts the defined relationship to one object value for the subject individual of the relationship. In other words, a *Functional* property links a source node from the domain with only one destination node from the range. For example, a person can be either male or female, and cannot have two gender values together. In this case, the person is the source node in the domain, where the gender type is the destination node in the range.

- *Inverse Functional*: each member in the domain can be linked to only one member in the range. *Inverse Functional* property indicates that the subject of a relationship is the only subject that can be linked with a specific relationship's object. If any other subject is linked to the same object, this means that the "other" subject is actually the same subject (Bechhofer 2015; Horridge 2011). For example, a person's ID serves as an *inverse functional* property for a person because each person has a unique person's ID.
- *Transitive*: this property infers ambiguous relationships from the explicit ones. If a property *T* is transitive and the following pairs (a, b) and (b, c) are instances of *T*, then the *transitive property* infers that the pair (a, c) is also an instance of *T*. For example, assume a "Consists" is a transitive object relationship. Building *B* is developed on a land object *Lot01*. Apartment *A* is part of the building *B*. Since *B* is developed on *Lot01*, and *A* is part of *B*, then the transitive relationship infers that *A* is also developed on *Lot01*. Figure 3.6 illustrates this *transitive property* relationship.

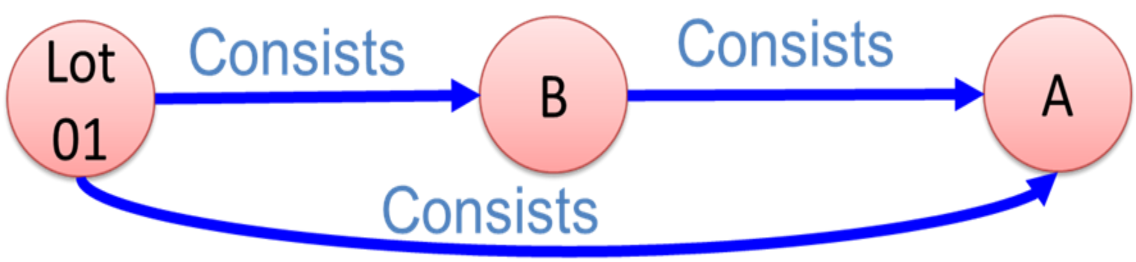

Figure 3.6. Transitive property

- *Symmetric*: assume *S* is a *symmetric* object relationship. If the pair (a, b) is an instance of *S*, then the pair (b, a) is an instance of *S*. For example: assume that "hasSibling" is a *symmetric* object relationship. Alex has a sibling, Tom. Then, the *symmetric* relationship infers that Tom has a sibling, Alex. Figure 3.7 describes this *symmetric* relationship.

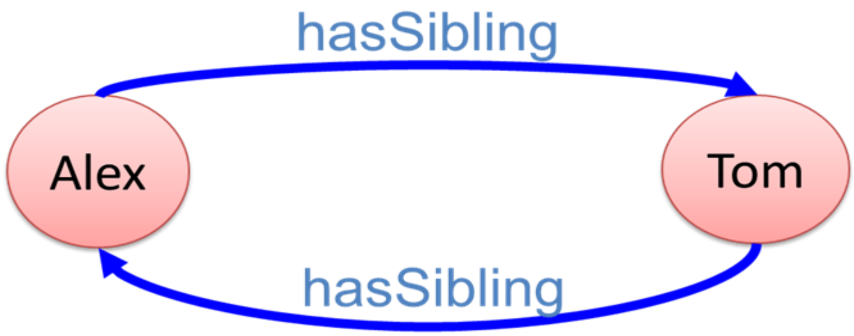

Figure 3.7. Symmetric property

- *Asymmetric*: it is the opposite of the symmetric one. This relationship property prevents the relationship from being reciprocated. If *A* is an *asymmetric* relationship and relates an individual *P* to an individual *D*, the *asymmetric* property prevents the individual *D* from relating back to the individual *P* through the same relationship. For example, assume "hasParent" is an *asymmetric* relationship. Alex is the father of Tom. Then, the relationship "hasParent" directs from Tom to Alex and cannot be reversed. Figure 3.8 describes this *asymmetric* relationship.

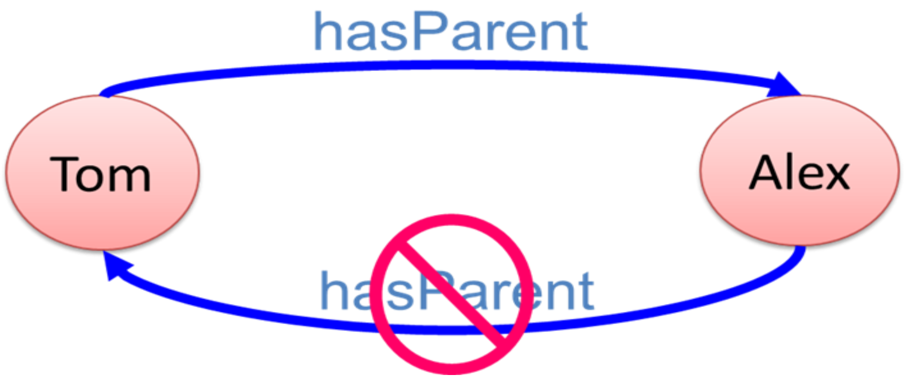

Figure 3.8. Asymmetric property

- *Reflexive*: it relates an individual to other individual and to itself as well. For example, assume "represents" is a *reflective* relationship. Alex represents Tom and himself. The *reflective* property allows the relationship to link Alex with Tom, and Alex with himself. Figure 3.9 describes this *reflective* relationship.

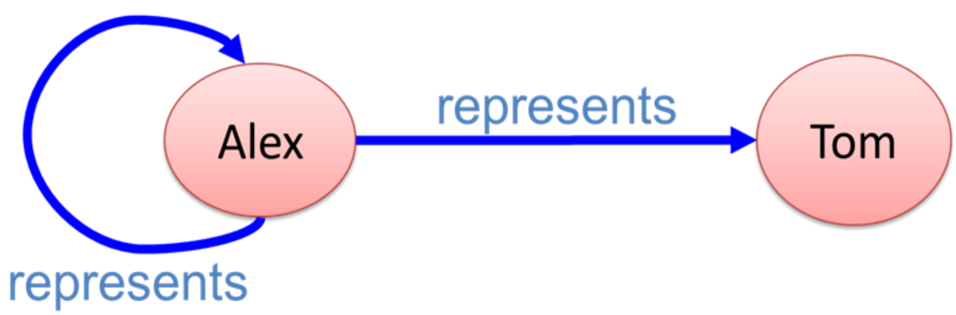

Figure 3.9. Reflective property

- *Irreflecive*: it is the opposite of the reflective relationship. It allows a relationship to link between two different individuals, but not to link the individual to itself. For example: assume "owns" is an *irreflective* object relationship. This relationship is to describe the ownership of a land object. Alex owns the land object Lot01. The *irreflective* relationship indicates that Alex is the owner of Lot01. Meanwhile, it prevents the relationship from looping back to Alex again. Figure 3.10 describes this *irreflective* relationship.

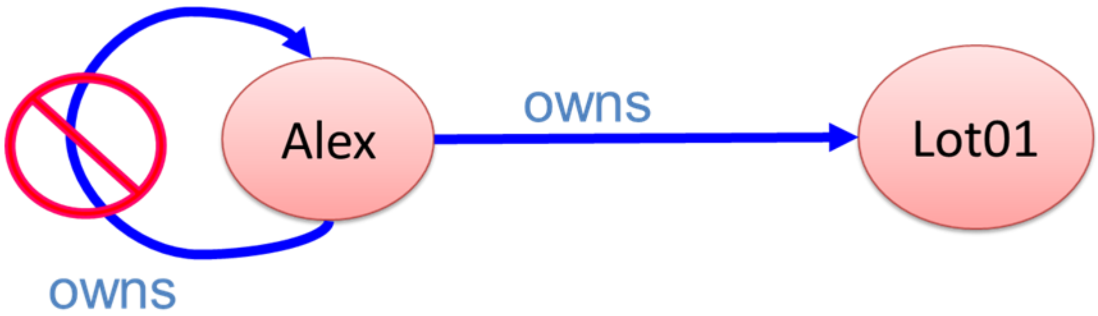

Figure 3.10. Irreflective property

Characteristics of the object property relationship include *Functional, Inverse Functional, Transitive, Symmetric, Asymmetric, Reflexive, and Irreflecive*. These characteristics are used to describe different types of tenure relationships. Some tenure relationships (*e.g.* asymmetric) may be mispresented by available LTISs. The author has chosen to use the Triple Store relationship characteristics to describe different types of relationships clearly and accurately.

2. **Data property relationship:**

The data property relationship describes the data value of an individual. This relationship type has only one trait, *Functional* property. This trait was categorized as an object relationship property (Bechhofer et al. 2015; Horridge 2011). The relationship between any person and her/his date of birth is an example of a *functional* data property relationship, where each person has one date of birth only.

In synthesis, section 3.4 discussed different database systems for the purpose of selecting the most suitable database system to design the proposed TTN database. To achieve this objective, the author eliminated the RDBS type due to its limitations and analysed the different database categories of the Non-RDBS type.

It was determined that the Graph Database category is more flexible in capturing and describing unstructured and complex datasets than the other database categories. Thus, the author focused on the Graph Database category and eliminated the other database categories. The Graph Database contains a list of database programs such as Triple-Store, HyperGraphDB, and Neo4j. Based on the characteristics and the challenges of complex situations, the most appropriate database program to use for developing the TTN database is the Triple-Store database.

The features and the functionalities of the Triple-Store database are well-suited for developing a flexible TTN database in conflict and post-conflict situations. It describes data as a network graph, which effectively illustrates social and tenure relationships. The graph network consists of nodes that are interconnected through relationships. The triple is the simplest form of Triple Store database. Each triple is composed of a subject, predicate, and object (*s*, *p*, *o*), where the subject and the object are nodes connected together via logical relationships called predicates. RDFS and OWL are ontology languages used to define the Triple Store database objects, relationships, and classes. RDFS and OWL can be used to build and facilitate data mining and social network analysis tools. All in all, the Triple Store database supports the integration of data mining and social network analysis techniques within the database design through a variety of features and functions.

3.5 Relevance to Research

The contents of the chapter addressed the following research questions:

1. What is the hypothesis that guides the proposed TTN database to support land tenure security and stabilize an unstable situation?

2. What is the most appropriate database system to use to develop and address the needs of a TTN database in conflict and post conflict situations?

To answer research question 1, the author developed a hypothesis called CPCLTL to guide the design of the proposed TTN. The CPCLTL describes the role that the TTN database plays in promoting stability in an unstable situation by bridging the gap between *de facto* and *de jure* in a region. The ability to adequately capture and describe data (in *de facto*) and to infer knowledge through the TTN will assist in bridging the remaining gap between *de facto* and *de jure* concepts. The integration between *de facto* and *de jure* will form the foundation necessary for ridding complexity and fostering a semi-stable situation.

The chapter applied Gregor and Jones' (2007) Information System design theory to outline components that were considered for the TTN database design. This research specifically contributes to the area of function in information systems design. To achieve the primary research objective (see chapter one, section 1.3.1), and answer research question 2, this chapter described, compared, and discussed different database systems in the context of land tenure information within complex situations and found the most appropriate database system to use in the development of the TTN database.

3.6 Conclusion

This chapter introduces the CPCLTL and uses it to conceptualize land tenure problems in conflict and post-conflict situations. It also depicts the author's vision of how the TTN database may secure land tenure and improve unstable situations over time. The CPCLTL aims to promote stability by bridging the existing gap between *de facto* and *de jure* in unstable situations. In order to progress up the ladder and increase stability, the social structure and *de facto* rules of land tenure practices must be understood within their societal context. A TTN database system needs to be developed to take this issue into consideration. To begin this process, Gregor and Jones' (2007) Information System design theory was outlined in section 3.3 to serve as a guide for the author's proposed design and to illustrate the author's contributions to methods and functions in information design. Section 3.4 described the features of an effective TTN database for conflict and post conflict situations. This chapter introduced and differentiated RDBS and Non-RDBS database systems. The author eliminated RDBS due to its limitations and explored a variety of Non-RBDS.

It was concluded that the Triple Store Database, a graph database system, is the most suitable one to use for conflict and post conflict situations because it is more flexible in capturing and describing unstructured and complex information compared to the other database categories. Section 3.4.1.1.1 discussed the Triple Store database in detail and argued that the Triple Store database is very supportive of data mining and social network analysis techniques. In section 3.4.1.1.1, the author illustrated how data was organized and constructed to depict relationships. This chapter contributed to the achievement of the main objective of this thesis by discussing the theoretical framework behind the TTN database and by identifying and justifying the most appropriate database to use. Chapter four will explore the research methodology in further detail.

Chapter Four: Database Development Methodology

4.1 Introduction

The objectives of this chapter are as follows:

- Describe the methodology used to develop a TTN database product for conflict and post-conflict situations.
- Evaluate the methodology used to design the TTN database by determining how the TTN database meets the desirable features of the TTN database design (see chapter three, section 3.4).

This chapter should be read in conjunction with an examination of Appendix C. The TTN database prototype tests are described in chapter five.

To achieve the objectives of this chapter, the contents of this chapter are divided into five main sections. The first section (section 4.2) describes the design method used to develop an adaptive and flexible TTN database for conflict and post-conflict situations. The second section (section 4.3) outlines the technical design of the TTN database prototype. The third section (section 4.4) evaluates the described technical design and methodology in sections 4.2 and 4.3 by discussing the resulting outcome of the methodology, the TTN database. The fourth and fifth sections (section 4.5 and 4.6) conclude with a discussion of how the methodology described relates to this thesis and the overall relevance of this chapter to the research.

4.2 Methodology

This section describes a set of methods and the process used to develop an adaptive and flexible TTN database product for conflict and post-conflict situations. To support land tenure security in the aforementioned situations, a flexible TTN database design is required that is capable of adapting to different disputed scenarios, capturing and manipulating unstructured data, and dynamically representing the complex social and tenure relationships. As argued in section 3.4.1, the TTN database is schema-less.

4.2.1 TTN database design method

To synthesize what has been established so far the methodology proposes a flexible initial system as a starting point for TTN database development. The author adapted Boehm's (1988) spiral model, which is a software development model. The spiral model is described in this thesis is aimed at an interdisciplinary audience, not merely computer scientists. The spiral model is one of the most flexible software development life cycle models; it incorporates elements of one or more process models such as incremental, waterfall, or evolutionally model(s) with a high emphasis on risk analysis (Osterweil 2011). This model is used to develop large and complex software projects that will need to be frequently refined and updated based on feedback. Figure 4.1 describes the Spiral model. As shown in figure 4.1, the Spiral model consists of four main phases (Osterweil 2011): i) determining objectives, alternatives, and constraints; ii) evaluating alternatives and risks; iii) product development; and iv) planning for the next iterations. These stages are repeated for each development cycle. The following describes each phase (Muhsen 2008; Barry 2000):

- Determining objectives, alternatives, and constraints: this phase determines the desired objective(s) of the software, such as system functionality, performance, and ability to accommodate change. In this phase, alternatives are addressed through the determination of tools, methods, plans, policies, and other facilities that are important for developing the software product (initial design A, design B, and etc.) The constraints can be the budget of the software project, security, schedule, and interface.

- Evaluating alternatives and risks: alternatives are evaluated based on the specified constraints and objectives in order to assess the risk(s) of the project.
- Product development: once risks have been assessed, a strategy for resolving these risks is adopted. Then, the development of the software prototype is undertaken through an iterative spiral approach.
- Planning for the next iterations: a plan to refine the software to meet new requirements is described in this phase.

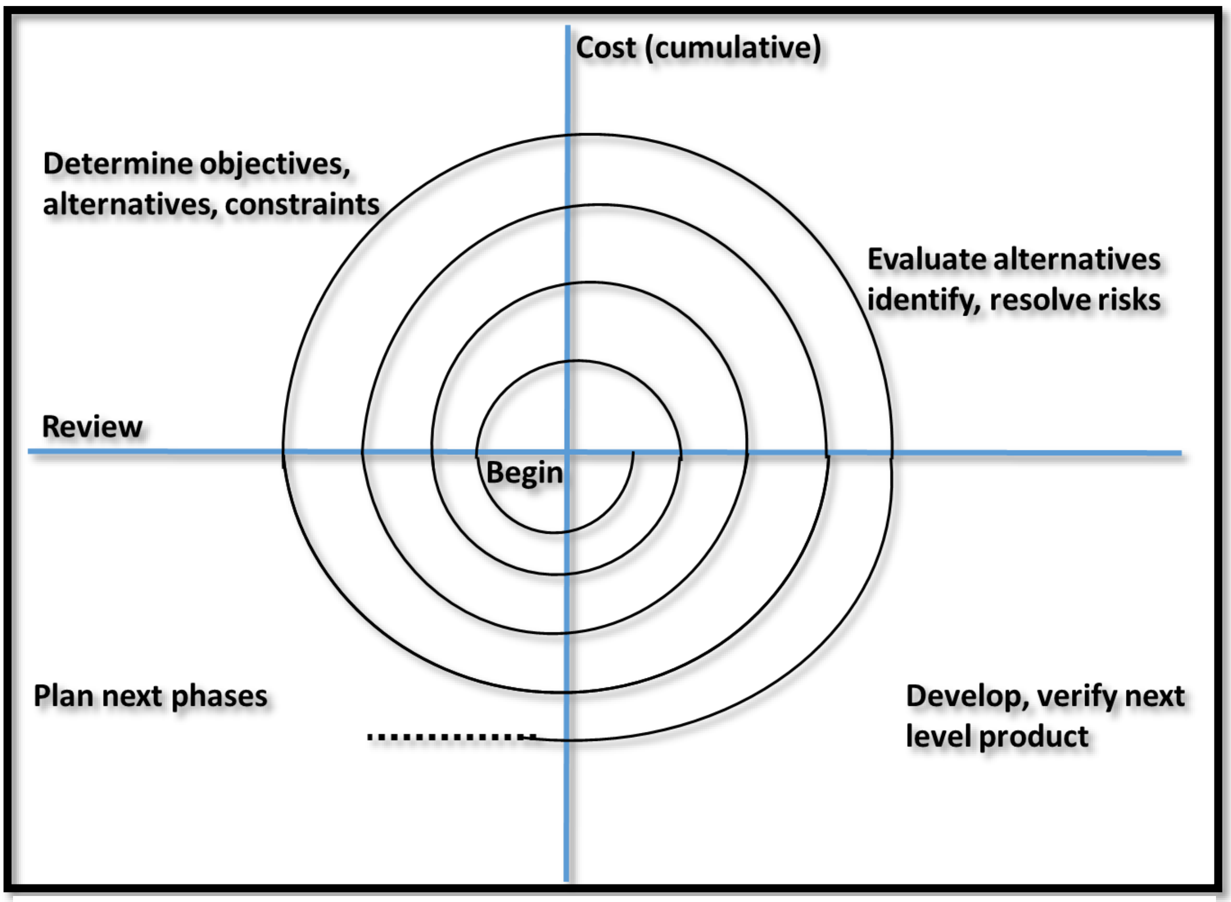

Figure 4.1. An abstract showing the key underlying ideas behind the Spiral Model (Osterweil L., 2011)

The justification for adapting this model is that spiral model supports software system refinement over time, which allows the system's adaptation in uncertain situations. According to Muhsen (2008), this model is appropriate for developing multifaceted projects that are intended to deal with uncertainty and changing requirements. As the TTN database needs to be flexible and adaptable to a great deal of complexity, uncertainty and change, Boehm's spiral model is the most suitable system to use. The initial TTN database is used for data collection and requirement elicitation. It evolves incrementally within time to suit a certain situation and meet the latest requirements. The Spiral model is adapted for the development of the TTN database design. Each phase of the Spiral model is addressed in different parts of the design methodology. Figure 4.2 describes the TTN database methodology. The following describes the three stages of the TTN database methodology:

1. Stage 1: the pre-design stage describes the initial step for designing a TTN database. Stage 1 considers the first phase of the Spiral model. This stage is based on the literature review conducted in chapters two and three. In stage 1, the characteristics of conflict and post-conflict situations were described, and the desirable features of the TTN database were determined (see chapter three, section 3.4). Also, tenure data for conflict and post-conflict situations were selected from the two real-world simulated scenarios (see Appendices A and B for conflict and post-conflict situations, respectively) and analysed.
2. Stage 2: the system design stage. Stage 1 builds on stage 2 by determining the requirements of the situations, which is developing an adaptive and flexible TTN database. The second phase of the Spiral model was considered for Stage 2. This stage describes the technical design of the TTN database, and how the desirable features of the design were achieved. The technical part is described in detail in sections 4.3 and 4.4. The outcome of this stage is the initial TTN database.
3. Stage 3: the implementation and evaluation stage. The third and fourth phases of the Spiral model were considered for Stage 3. Within this stage, the initial TTN database design was

tested against two real-world simulated land tenure scenarios for conflict (see Appendix A) and post conflict situations (see Appendix B). The TTN database test and its results are discussed and evaluated in chapter five. Based on the system evolution, the TTN database is refined in order to meet additional requirements. As shown in figure 4.2, recommendations received from stakeholders are implemented in “Change request?” which allows for two types of refinement in the implementation and evaluation stage. Refinement is determined through the following two output choices that link stage 3 back to stage 2:

- “Yes” allows the TTN database to be refined through the addition of more nodes and links that are required for capturing new types of tenure information.
- “No, but we need to develop more DM&SNA” means that there is no need to refine the TTN database itself, but more data mining and social network analysis tools are required.

The evaluation of the system (TTN database) is carried by the users of the system (*e.g.* stakeholders) and through their recommendations and feedback it is modified.

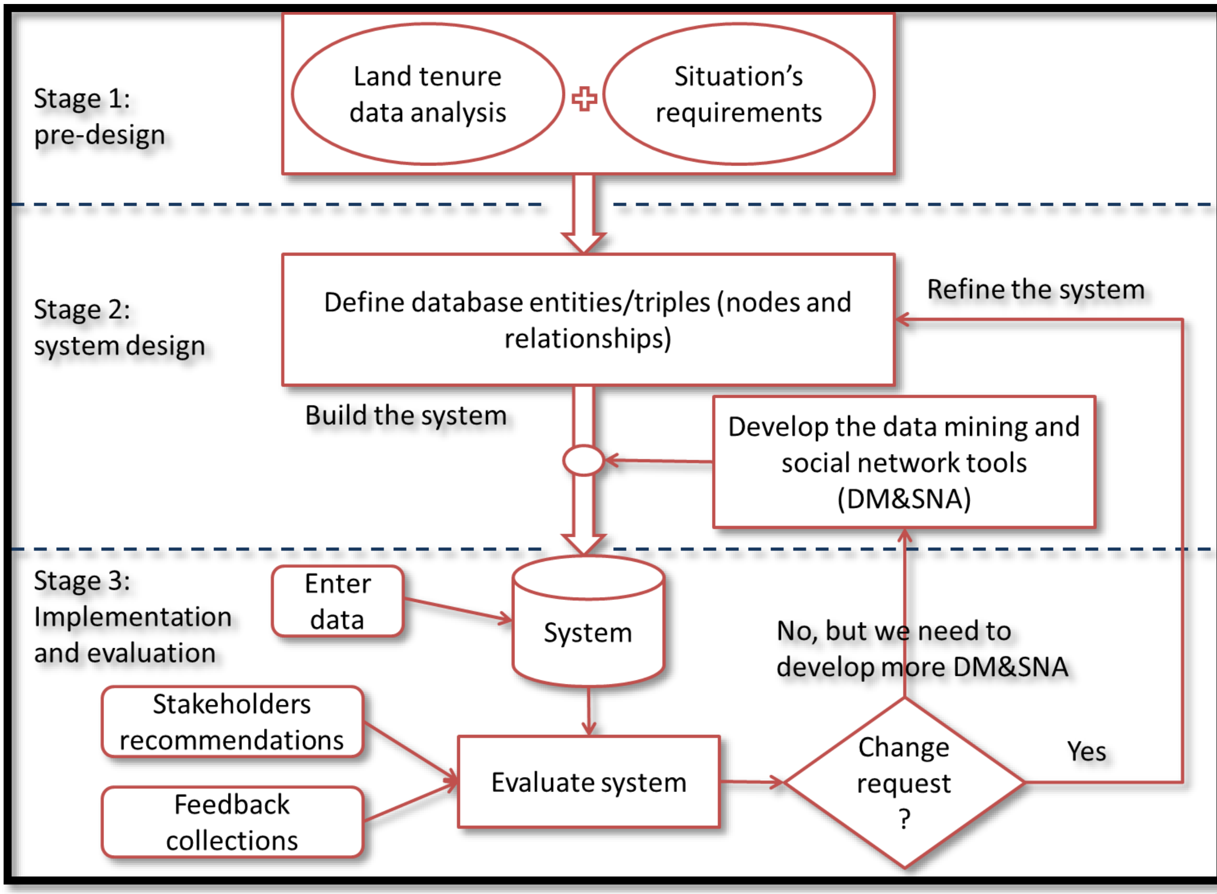

Figure 4.2. TTN database methodology

The next section describes the technical design of the TTN database and its conceptual design model.

4.3 TTN database design technical description

This section briefly illustrates the technical TTN database design, while specific details of the technical design are described in Appendix C, where the author programmed all the TTN classes, sub-classes, and relationships. These classes, sub-classes, and relationships were defined based on the data from the conflict and post-conflict situations.

As argued in sections 3.3 and 3.4.1.1.1, the Triple Store database was used to design the database because it supports flexible and provides an acceptable degree of robustness through handling billions of nodes and relationships. In addition, the ontology languages of the Triple Store database, RDF, RDFS, and OWL, were used to achieve the following:

- Model data in binary unidirectional relationships.
- Add semantics to the defined models.
- Integrate data mining and social network analysis techniques within the TTN database as built-in tools.

To perform the TTN database design, Protégé 4.3 software, an open-source ontology editor and framework for building intelligent systems, was used as a tool throughout the whole project (Noy and McGuinness n.d). This software was selected because it supports the RDF, RDFS, and OWL ontologies. Also, the Protégé software has an interface for data entry. This form can be used to test the technical TTN database design (Noy and McGuinness n.d). To develop the TTN database design model, the author considered the following:

- Challenges of conflict and post-conflict situations and agents' needs, all of which contributed to designing the optimal TTN database (see chapter two, sections 2.3).
- Desirable features of the TTN database design (see chapter three, section 3.4).

Tenure information is captured and represented through the TTN's nodes and links. The TTN's nodes capture and describe tenure objects, people, documents, tenure claims and transactions, and any other relevant objects. The TTN links capture and describe tenure relationships among the different tenure objects, people, tenure claims and transactions, and any other relevant objects. Data is structured in the TTN database in the form of classes and sub-classes that were defined based on the conflict and post-conflict situations. Figure 4.3 is an example that shows how the TTN database structures tenure information in the form of classes and sub-classes. The figure describes the *Person* class that consists of a set of sub-classes: *Parent*, *Daughter*, *Father*, *Mother*, and *Son*.

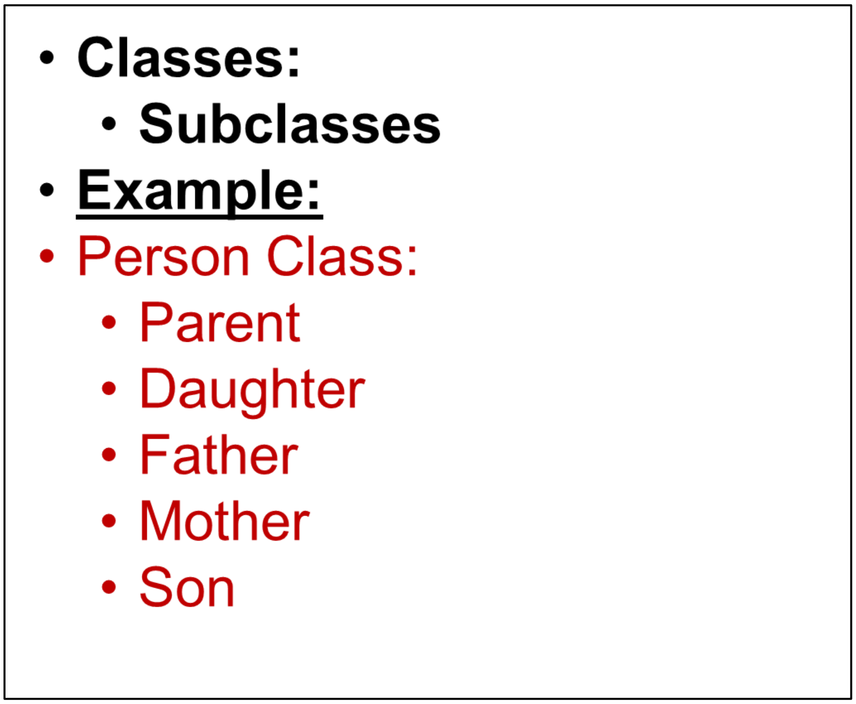

Figure 4.3. TTN Data Structure

The TTN database classes and sub-classes are defined based on their relationships. Figure 4.4 shows how the TTN database defines the *Parent* class. As shown in figure 4.4, the TTN database describes the person as a parent if the person is a member of the *Person* class and has a *hasChild* relationship with another person that is member of the *Person* class as well. This relationship is defined in the form of a triple (subject, predicate, and object) and modeled using the RDF ontology language. Appendix C.1 describes all the TTN database classes and sub-classes.

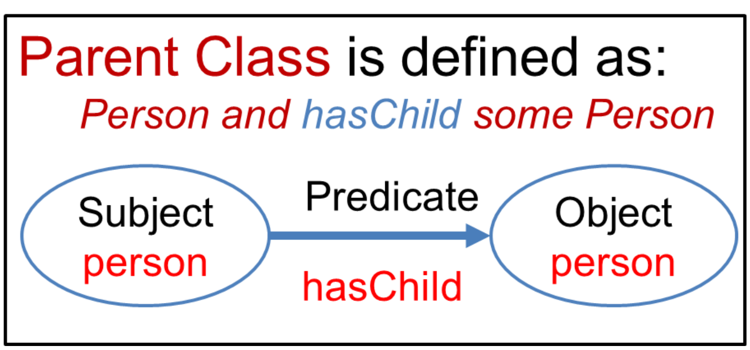

Figure 4.4. Parent Class Definition - TTN Database

Regarding tenure relationships, the TTN database uses two types of relationships to model tenure relationships. The first type is an Object Property relationship, which describes tenure relationships between objects. The second type is a Data Property relationship, which describes tenure relationships between objects and values (*e.g.* number and string). Figure 4.5 shows an example of how the TTN database models tenure relationships using the Object and Data Property relationships.

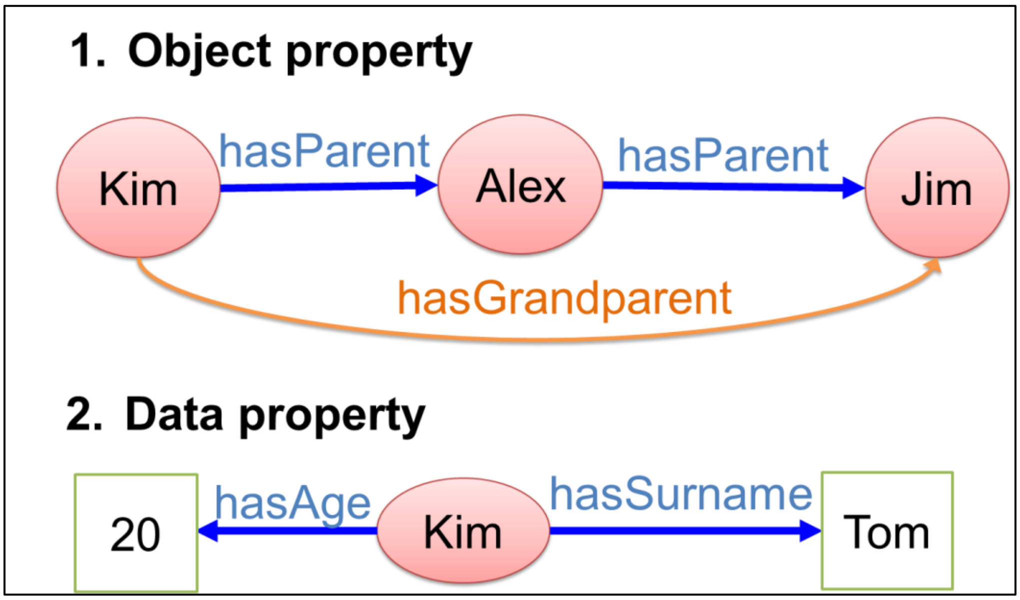

Figure 4.5. TTN Data Modelling

As shown in figure 4.5, the Object Property relationship is used to model different relationships between different persons: Kim, Alex, and Jim. The blue unidirectional link that is labeled as *hasParent* describes the parent-son relationship. Figure 4.5 shows that Alex is the parent of Kim and the son of Jim. The orange unidirectional link is the relationship inferred by the TTN database based on a chain of two *hasParent* relationships. The inferred relationships describe a grandparent-grandchild relationship between Kim and Jim. Regarding the Data Property relationship, figure 4.5 shows an example where the personal information about Kim, surname and age are described. Further descriptions about the TTN database Object and Data Property relationships are covered in Appendix C.2.

The TTN database captures and describes tenure information in the form of triples modeled by RDF. For example, Kim has a parent named Alex. The TTN database captures and stores this information in the following way:

<rdf:subject> Kim </rdf:subject>

<rdf:predicate> hasParent </rdf:predicate>

<rdf:object> Alex </rdf:object>

Kim is the subject, *hasParent* is the predicate, and Alex is the object. The TTN database stores data into one text file. Figure 4.6 shows a sample of the TTN database code. The code describes how the TTN database captured and stored the two *hasParent* relationships, and inferred the *hasGrandparent* relationship shown in figure 4.5 using RDF, RDFS, and OWL ontology languages.

```
<owl:ObjectProperty rdf:about="http://www.semanticweb.org/#hasGrandparent">
  <rdfs:domain>
    <owl:Restriction>
        <owl:onProperty rdf:resource="http://www.semanticweb.org/#hasGrandparent"/>
        <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/#Person"/>
    </owl:Restriction>
  </rdfs:domain>
  <rdfs:range>
    <owl:Restriction>
        <owl:onProperty rdf:resource="http://www.semanticweb.org/#hasGrandparent"/>
        <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/#Person"/>
    </owl:Restriction>
  </rdfs:range>
  <owl:propertyChainAxiom rdf:parseType="Collection">
   <rdf:Description rdf:about="http://www.semanticweb.org/#hasParent"/>
    <rdf:Description rdf:about="http://www.semanticweb.org/#hasParent"/>
   </owl:propertyChainAxiom>
</owl:ObjectProperty>
```

Data captured and stored

Unidirectional link

Inference

Figure 4.6. ***hasGrandparent*** **relationship**

The section in the code above labelled "Data captured and stored" shows how the TTN database captured and stored the *hasParent* relationships, while the section in the code labelled "Unidirectional link" shows how these relationships are captured and described in a unidirectional way. The last few lines of the code illustrate how the database inferred the *hasGrandparent* relationship from the two *hasParent* relationships.

Based on tenure information analysis in conflict and post-conflict situations, tenure information can be simplified as a set of triples: subjects, predicates, and objects. Therefore, the conceptual design model of the TTN database is modelled based on triples. Figure 4.7 describes the conceptual database design model of the TTN database.

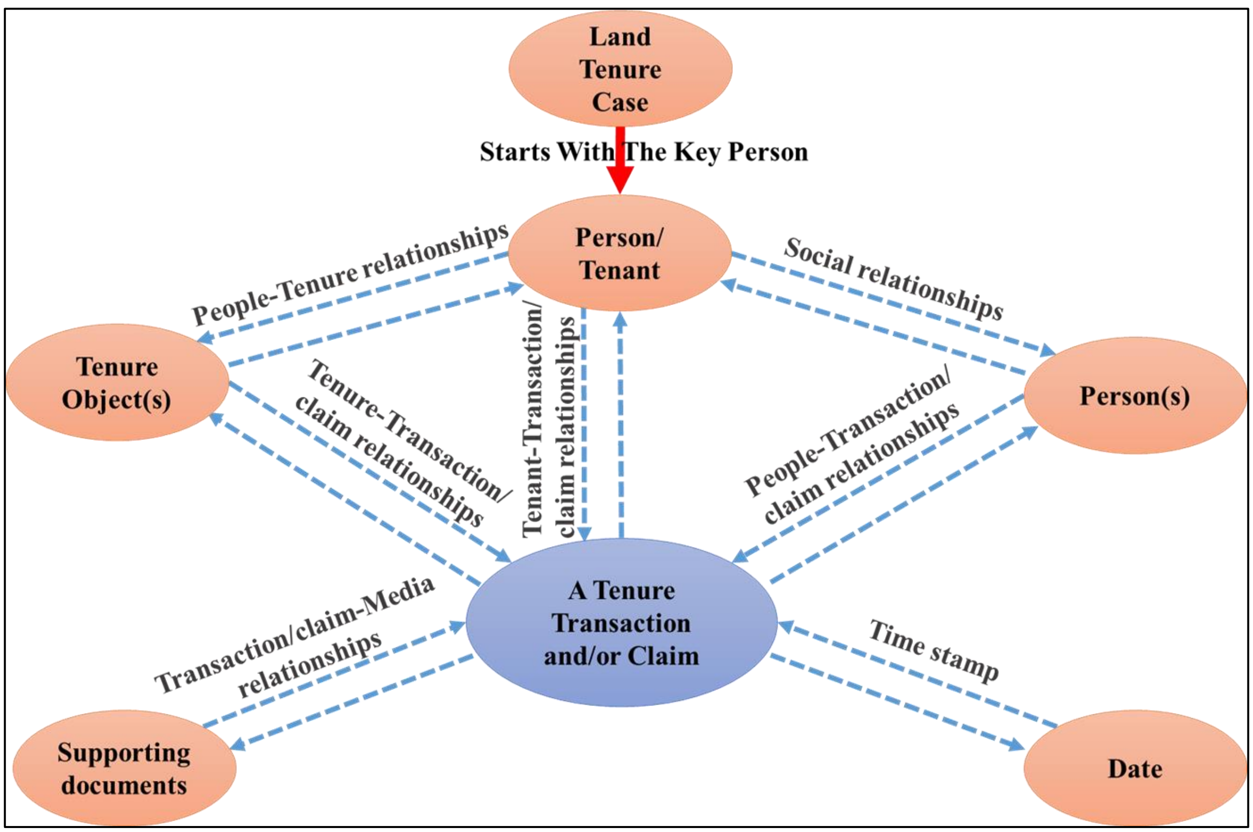

Figure 4.7. TTN conceptual database design model

As shown in figure 4.7, the model is comprised of the following main classes and relationships (these classes, subclasses, and relationships are further defined/detailed in Appendix C):

- *LandTenureCase*: is a tenure scenario that describes a tenure claim and relevant tenure historical claim(s) and/or transaction(s). It captures and provides a brief description about a land tenure dispute (scenario). Specifically, it demonstrates a land conflict scenario in different periods of time, and it describes the area of the conflict. This class consists of different sub-classes to capture and describe the different aspects of a tenure scenario such as the area of the conflict, the unique land tenure case Identification (ID) of the case, the alias of a land tenure scenario, and the brief description of the case.
- *Person/Tenant* and *Person*: these classes describe the different social roles that a person may have in a land tenure scenario. The *Person/Tenant* class is mainly for capturing and describing the person who plays the role of a tenant in a specific scenario, while the *Person* class is for capturing and describing the social roles of people who have relationships with the tenant such as witness, lawyer, representative, land professional, and elder. Also, it describes other roles that a person may have in her/his own family and/or extended family such as parent, mother, father, wife, husband, uncle, daughter, son, and sibling. Therefore, the *Person* class consists of sub-classes to describe different social roles. For example, person *A* can be described as a renter, witness, inheritor, seller, and buyer in a land tenure conflict scenario. As well, person *A* can be described in different social roles such as the father of person *F* and the son of person *S*. This pluralism in roles needs to be captured and described well, especially in inheritance land disputes.

- *TenureObject*: captures and describes different types of tenure objects. A tenure object can be one of the following types: a land object, or a development. In the experimental work, the development type consists of the following sub-types: cultivated field, fruit trees, building, shelter, shop, house, apartment, and garage. Tenure objects are distributed among these classes based on their established relationships. Therefore, the *TenureObject* class consists of different subclasses to describe the different types of tenure objects.
- *SupportingDocuments*: captures and describes different types of supporting documents that can be used to support a claim or a historical tenure transaction such as, deeds, scanned documents, pictures, and videos.
- *TenureTransaction and/or claim*: captures and describes the possible formal and informal historical tenure transactions such as expropriation, inheritance, rent, purchase/sell, and suspension. Also, it captures and describes different types of claims including ownership, inheritance, and rent between individuals on a tenure object. Therefore, this class consists of different subclasses which describe the different types of tenure transactions and claims. This class is the core class of the TTN database as it improves the flexibility of the TTN database in capturing and describing tenure relationships through capturing tenure information in the form of tenure transactions and claims. This class is embedded implicitly within the conceptual design models of the developed LTISs, such as TTS and STDM. It is important to regard tenure transactions and claims as a separate class (entity) that interconnected with all other classes (entities) in the TTN database, in order to simplify the complexity of tenure relationships in conflict and post-conflict situations. Tenure scenarios are expressed as

a series of transactions and claims, and the multiple roles that a person may have are represented in different scenarios through these transactions and claims. These different transactions and claims can assist disambiguation of relevant information.

Each class and subclass has a specific set of relationships. Individuals can be distinguished and distributed based on their established relationships within and between different classes. The relationships between individuals in a class were described through directed links, where each link has a source node and a destination node. The node within this context is an individual.

Different types of tenure relationships that are significant in conflict and post-conflict situations can be described in the TTN database. One of these types is called an asymmetric relationship. This relationship type describes relationships between two parts which are not equivalent or equal, such as a relationship between a landlord and a tenant, or a son and his father. In the TTN database design, the possible different types of social and tenure relationships on the ground were defined including the following relationships: person–person, person-tenure object, person-tenure transaction, person–claim, person-land tenure scenario, tenure object-tenure transaction, tenure object-claim, supporting document-tenure transaction, and supporting document-claim.

To recap on section 4.3, the TTN database was developed in a way to capture tenure information and historical conflict scenarios in the form of tenure claims and transactions (*e.g.* purchase/sell and inheritance). To support data mining and social network analysis techniques, RDF, RDFS, and OWL ontology languages were used to define and describe the defined relationships and the classes of the TTN database. These definitions enable the TTN database to achieve the desirable features of the TTN database.

4.4 TTN database design evaluation criteria

The section analyses and evaluates the TTN database design based on its ability to meet the desired functional requirements prior to the prototype test. The requirements consist of the following:

- How the TTN database captures and describes tenure information.
- How the TTN database permits further development without causing the database design to collapse.
- How the TTN database supports data mining and social network analysis techniques.

Then, the section concludes by illustrating how the TTN database meets the requirements above in ways that are different than STDM and TTS.

4.4.1 Capturing and describing tenure information

The TTN database can be defined as a descriptive system for land tenure claims. Figure 4.8 describes how the TTN database captures a land tenure scenario. More detailed descriptions of classes and relationships are included in Appendix C. As shown in figure 4.8, the *LandtenureCase* and the *Person* classes contain the *CaseID* and *Tenant* sub-classes, respectively.

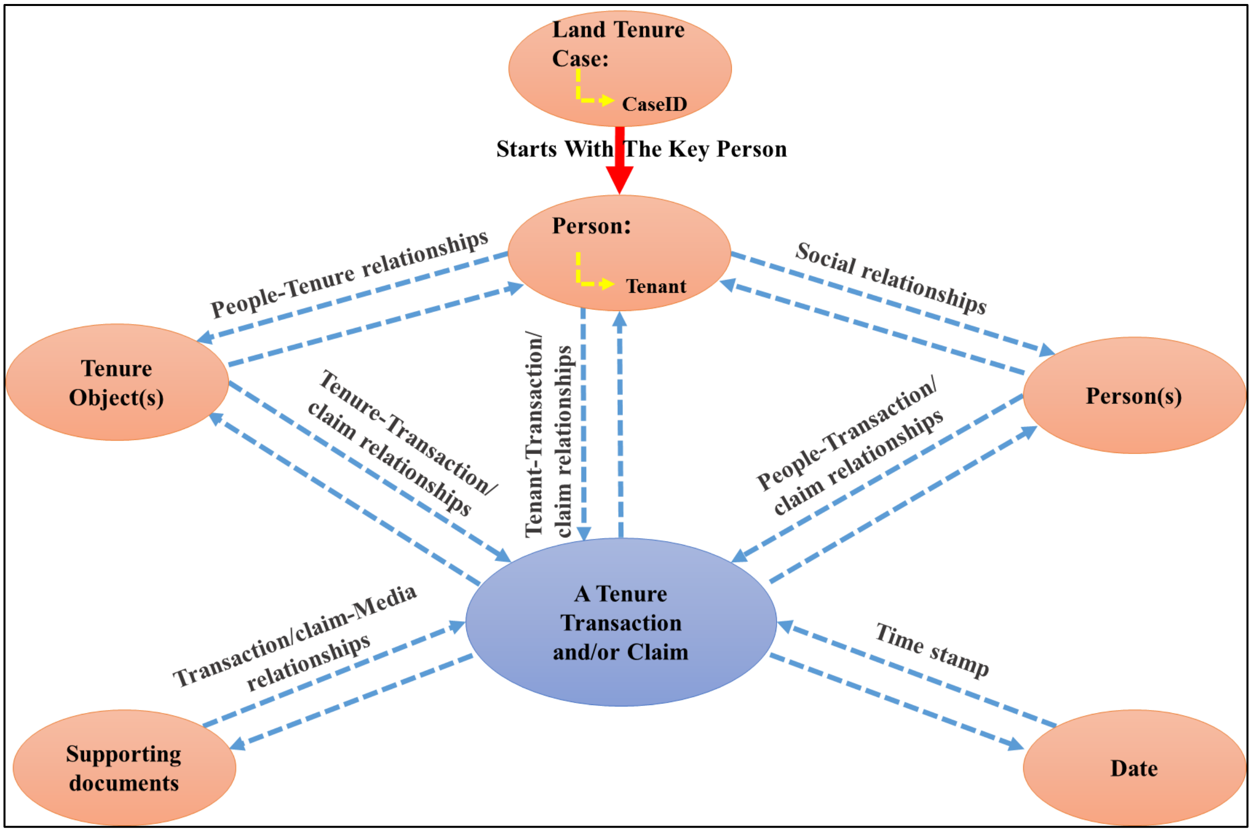

Figure 4.8. How TTN database captures a tenure case

To capture a land tenure scenario, the TTN operator should begin with entering an ID for the scenario as an individual in the *CaseID* class. For example, a unique code that can be used to distinguish one claim from another as an individual in the *CaseID* class. In the context of this research, individual refers to any data entered for a class. Then, the key person in the scenario should be entered as an individual in the *Tenant* class. The key person in this context the original owner of the disputed land object. Afterwards, the *CaseID* individual (scenario ID) should be linked with the entered individual in the *Tenant* class through the *StartsWithTheKeyPerson* relationship. Then, the individual of the *Tenant* class can be linked with different pre-entered individuals from the *Person*, *TenureTransaction*, and *TenureObjects* classes to describe a tenure scenario. The entered individuals in the TTN database are distributed among classes based on their relationships. Therefore, a TTN database individual can be described in different forms if it is classified in more than one class. For example, a person can be a witness and a tenant, meaning the person is described as a witness in the *Witness* class (see Appendix C.1) and as a tenant in the *Tenant* class.

The relationships of the TTN database were defined to perform two functions: to establish relationships among classes' individuals and to define classes' characteristics where each class has its own possible defined relationships. For example, we might define two classes as *RentTransaction* and *SellingBuyingTransaction.* The relationships embodied in the *RentTransaction* class are not the same as those of the *SellingBuyingTransaction* ones (see Appendix C.2). To describe a rent transaction, a set of relationships should be established, such as: *hasLessee* and *hasLessor* (see Appendix C.2). On the other hand, to describe a *selling/buying* transaction, relationships should be establish as *hasBuyer* and *hasSeller* (see Appendix C.2). Based on the established relationships, captured tenure objects can be classified.

The TTN database is flexible in capturing and describing different details. By envisioning tenure relationships as nodes and links, new information can be added easily. Therefore, the above design of TTN database should capture and describe existing and new information in order to represent different layers of complexity as well as growing complexity. This is seen as a critical user need for a LTIS in conflict and post-conflict situations.

4.4.2 Permitting Further Development

Since the TTN database is primarily developed for dynamic situations, the TTN database permits further development easily. New tenure objects and relationships that had not been considered in the initial TTN database design can be captured. Simply, a new tenure object can be captured by creating a new class node with the appropriate relationships. For instance, assume a specific type of land, *TypeX,* is not defined in the initial iteration of the TTN database. A new class node can be added to capture the new type of land, *TypeX*, as individuals of the created class. Then, the individuals of the class node, *TypeX*, can be described by defining the appropriate tenure relationships that are linked with the individuals of the *TypeX* class. If the *Tenure* class is defined before but the TTN is missing a specific type of tenure relationships to describe a relationship between two individuals; the TTN database supports the addition of a new type link to describe a specific type of relationship. Adding new nodes and relationships in the TTN database is straightforward because of the schema-less model of the TTN database (see section 4.2). This is one of the justifications for using a schema-less design model for the development of the TTN database.

4.4.3 Supporting data mining and social network analysis

The ontologies that describe the TTN classes and relationships enable the TTN database to reveal hidden tenure relationships and investigate social networks within the database itself, automatically. When information is entered, the reasoner navigates connected components (nodes and links) to trace, investigate, infer, and validate the meaning of the entered data's classes and relationships. For example, if a person *A* is defined explicitly as the father of persons *B* and *C*, then the database infers that *B* and *C* are siblings, because they have the same father. Also, if person *C* has son *S*, the TTN database infers that *A* is the grandfather of *S*, and *B* is the uncle of *S* automatically. Moreover, the TTN database detects illogical relationships or any contradictions among individuals. For instance, if in another scenario, person *C* is described as the father of person *B* or *A*, the database detects this relationship and describes it as an illogical relationship (which may be indicative of fraud) under the *NoThing* relationship. This relationship is a built-in relationship in the Triple Store database to describe illogical relationships. Also, the TTN database describes illogical membership of classes under the *NoThing* class. For example, if a person *A* is entered as an individual in the *TenureObject* class, the database classifies the person under the *NoThing* class.

Data mining and social network analysis techniques are well supported in the TTN database because the Triple Store database and its ontology languages support the integration of these techniques as built-in tools. Instead of defining each relationship specifically, the database establishes and defines the social patterns that describe different relationships through RDF, RDFS, and OWL. For instance, mother-daughter/son, father-daughter/son, sibling-sibling, uncle-nephew/niece, and etc. are all defined in the TTN database as being unidirectional; when a new relationship is added, the system determines whether that relationship is that of mother-daughter/son, father-daughter/son, sibling-sibling, or uncle-nephew/niece based on the social patterns that have been programmed into the system. Similarly, when new tenure relationships are added, the ontology languages (RDF, RDFS, and OWL) of the Triple Store database enables the TTN database to describe those relationships based on the given/programmed tenure patterns.

4.5 Relevance to research

The contents of this chapter contribute to achieving the overall objective of the thesis by addressing the primary research objective of the research (see chapter one, section 1.3.1) and answering the following research questions:

1. Which database design offers a solution that is best suited for conflict and post-conflict situations? And how can it be achieved?

2. How can data mining and social network analysis techniques be integrated with the proposed database design in order to make the design more effective?

Addressing these questions enabled the author to design an adaptive and flexible schema-less TTN database for conflict and post-conflict situations. Questions 1 and 2 were answered through the development of a methodology for designing a schema-less TTN database based on Boehm's (1988) spiral model. The product resulting from the illustrated methodology in section 4.2 is the TTN database. Data mining and social network analysis techniques are integrated within the TTN database design as built-in tools. The TTN database design was evaluated based on the requirements that were outlined in section 4.3. The technical details of the TTN database design were described in Appendix C. To conclude, the contents of this chapter add to a growing body of literature on Principles of form and function, more specifically functional flexibility in conflict and post conflict situations, in LTIS design theory (see chapter three, section 3.3).

4.6 Conclusion

This chapter is the foundation of the research. The chapter described the methodology and the design process used to develop the TTN database design in sections 4.2 and 4.3. The methodology adapted the Spiral software development model to develop the TTN database prototype. Phases of the Spiral software development model were incorporated in the methodology. The methodology consisted of three main stages: pre-design (phase 1), system design (phase 2), and implementation and evaluation (phases 3 and 4). The implementation and evaluation stage is reiterative, linking back to the system design stage to update and refine the database design in order to meet new needs on the ground. Moreover, the implementation and evaluation stage is connected to data mining and social network analysis tools in the system design stage, which permits further development, if required, by stakeholders. The final product of the illustrated methodology is a TTN database.

The concept behind the TTN database design is that conflict and post-conflict situations are primarily in need of a flexible and adaptive database system that is able to capture and describe tenure information and relationships in a flexible way. The Triple Store database program—a NoSQL database system—was used to design the TTN database through a schema-less database design model. Triple Store database ontology languages, RDF, RDFS, and OWL, were used to integrate data mining and social network analysis techniques in the TTN database design.

The TTN database design was evaluated in section 4.4 against its desired features. The TTN database captures land tenure scenarios in the form of tenure claims and transactions. Different classes and relationships were defined to capture and describe different tenure objects and relationships. The TTN database distributes the captured information among appropriate classes automatically, which helps to describe the captured tenure information in a flexible way. The TTN database describes the captured information in the form of a network (nodes and unidirectional links). Also, the integrated data mining and social network analysis techniques are used to investigate the social network and reveal hidden tenure information and relationships automatically.

The next chapter tests the TTN database against two case studies, Palestine for conflict situations and Somaliland for post-conflict situations.

Chapter Five: TTN Database Prototype Test

5.1. Introduction

This chapter expands on the technical description of the TTN database design. The author developed the TTN database and simulated the data to test the TTN database. This chapter tests the TTN database using two simulated land tenure scenarios based on real-world situations: the ongoing conflict in Palestine (see Appendix A), and the post-conflict situation in Somaliland (see Appendix B). This experimental test has two purposes. The first purpose is to examine the functionalities of the TTN database prototype to ensure that the TTN database meets its requirements (see chapter three, section 3.4). The second purpose is to determine the limitations of the TTN database. Finally, to reveal the versatility of the TTN database and what it offers, the author compared it to another available database. The author aimed to compare the TTN database with TTS for two main reasons. To recap, the first reason is that the concept and the philosophy of TTS was considered when designing the TTN database. The second reason is that TTS and TTN are both specifically developed to capture and describe complex tenure relationships in complex situations (see chapter two, section 2.5.2.1 for more detail). Using TTS to capture and describe the two simulated scenarios can underscore important features of the author's database design, the TTN database, as compared with other database designs. The results of the two database systems were analysed and discussed. This chapter should be read in conjunction with Appendices A, B and D.

The topics of this chapter are discussed in the following order: (i) data; (ii) database design test; (iii) results and discussion; and (iv) similarities and differences between the TTN database and TTS. Finally, the chapter closes with (v) relevance to research; and (vi) conclusion.

5.2. Data

Two simulated land tenure scenarios were used to achieve the test and compare the results of the TTN database prototype with those of TTS. One of the two scenarios describes a multifaceted land tenure dispute among family members and their next-door neighbour in the Gaza Strip, a conflict situation. The second scenario describes a multifaceted land tenure dispute among different clans and sub-clans in Somaliland, a post-conflict situation.

The Gaza Strip and Somaliland scenarios and their relevancies and limitations are described in Appendices A and B, respectively.

5.3. Database design test

The section describes an experimental test developed by the author to examine the TTN database prototype. The Protégé software, an open-source ontology editor and framework for building intelligent systems, was used to conduct the test because it is supported by a graphical user interface that compiles with RDF, RDFS, and OWL ontologies. The purpose of this test is to determine if the TTN database meets the following functions:

- Captures and describes, in a flexible way, land tenure information, despite its complexity.
- Automatically investigates the tenure network and reveals hidden tenure information.

The TTN database was tested for these functions, because they are critical to supporting tenure security in both conflict and post-conflict situations. The data used to test the TTN database was derived from two real-world simulated scenarios: Palestine (conflict situation) and Somaliland (post-conflict situation).

The following section illustrates and discusses the results of a TTN database test, which examined the following functions: entering tenure information, supporting data mining and social network analysis techniques, and describing tenure information. Figure 5.1 below provides a graphical representation of the testing process.

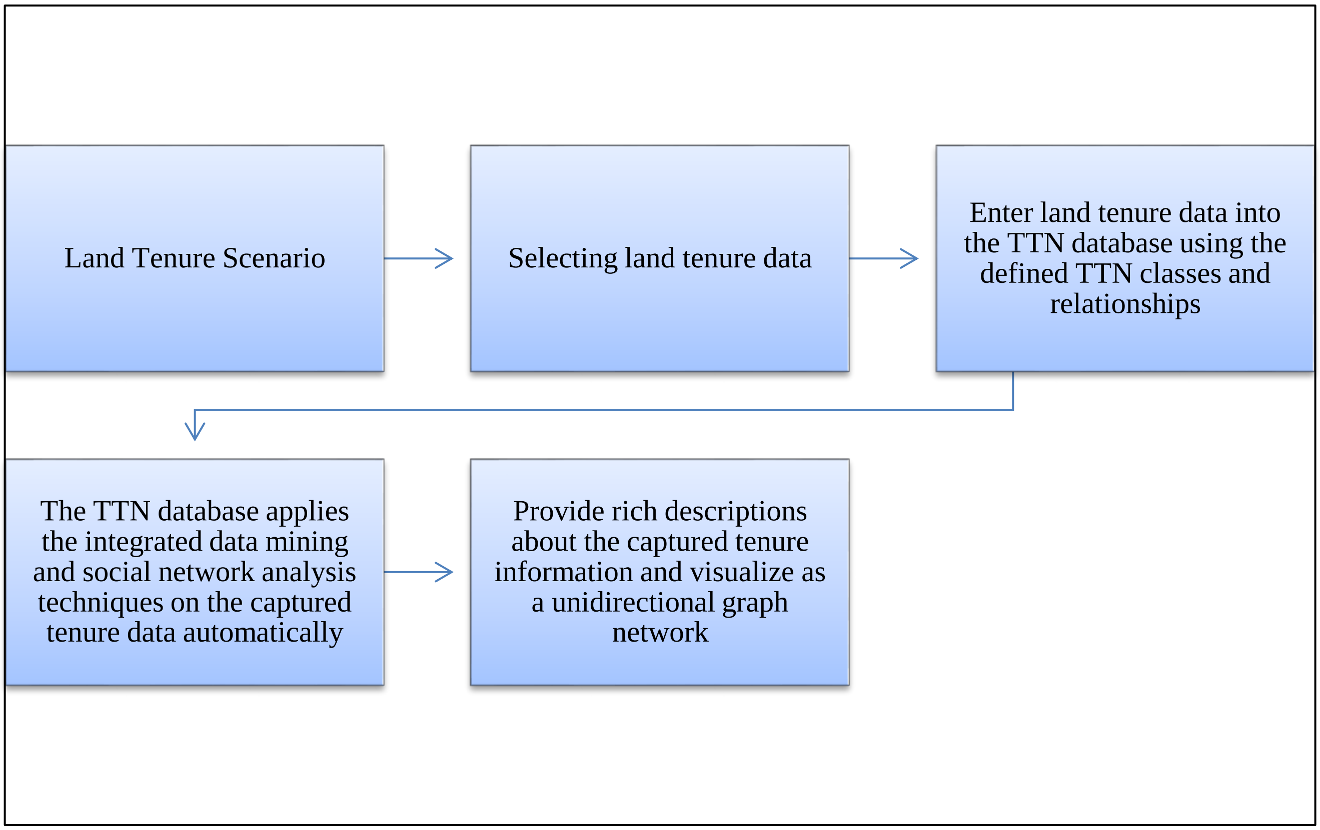

Figure 5.1. TTN testing process

5.4. Test results and discussion

This section illustrates and discusses the results of the TTN database by entering the tenure information of the simulated Palestinian and Somaliland tenure scenarios as described in Appendices A and B, respectively. The following subsections describe and analyse the results of the test. Appendices A.1 and B.1 provide a list of the sub-classes used and tested for the Palestinian and Somaliland scenarios, respectively. Further analysis of the test results for the Palestinian and Somaliland scenarios are described in the aforementioned appendices.

5.4.1 Entering tenure information

This section tests the TTN database's ability to capture tenure information. To achieve this task, tenure data from the Palestinian and Somaliland scenarios were selected and entered into two separated TTN databases. The tenure elements of the two scenarios (*e.g.* people, tenure objects, supporting documents, and claims) were entered as individuals of the following classes:

- Person/tenant.
- Tenure transaction and/or claim.
- Tenure object.
- Supporting documents.

Meanwhile, the author established the corresponding tenure relationships. For example, each tenure transaction or claim has supporting documents, a date, tenure objects, etc. While entering the scenarios, the author took notes about the changes that occurred in the data, and used these changes as feedback to refine the TTN database. The TTN database needed to be refined iteratively to capture new tenure objects, as subclasses of the defined classes, and to capture relationships in the two scenarios that had not been considered in the initial TTN database design. In addition, data mining and social network analysis techniques were adjusted in order to consider the newly added subclasses and relationships. Refining the TTN database was easy because the TTN database is schema-less (not rigid), which supports the iterative refinement process. The schema-less model of the TTN database supports its adaptation in dynamic political and social situations, which is important for capturing complex and unforeseen tenure claims in conflict and post-conflict situations.

Detailed results from the tenure information entered for the Palestinian and Somaliland scenarios are illustrated in Appendices A.5.1 and B.4.1, respectively. The results show that the TTN database was able to capture tenure claims and disputes easily without affecting data integrity. Not all TTN sub-classes were used in these tests. The TTN classes used in the tests were able to capture relevant tenure information from the scenarios which the TTN database represented in a schema-less way through sets of triples consisting of nodes and links. It was able to capture the different elements of the two scenarios, such as people, land objects of interest, claim/tenure transaction, supporting documents, and different tenure relationships. Regarding people, the TTN database is able to capture all the relevant participants' information such as name, gender, birthdate, etc. The TTN database is also able to capture different social relationships between people.

Regarding land objects of interest, the TTN database is able to capture all the relevant information and detail about a land object (*e.g.* lot number, type of land, address, cadastral information, etc.) Moreover, the TTN database is able to capture different historical tenure relationships between land objects (*e.g.* division operations, merging operations, changing land type, and etc.)

Regarding claim/tenure transactions, the TTN database is able to capture all the relevant information about a claim through different details (*e.g.* claimer, time stamp, the court of the claim, claim object, and claim parties). The TTN database is able to capture different historical tenure transactions and claims that are relevant to the claim of interest which is the most recent submitted claim.

Regarding supporting documents, the TTN database is able to capture all the relevant supporting documents that are related to a tenure claim and/or transaction. As well, the TTN database is able to capture the different relationships between these documents.

Finally, the TTN database is able to capture different tenure relationships between the different types of aforementioned objects: people-people, land-land, claim/tenure transaction-claim/tenure transaction, supporting documents-supporting documents, tenure-people, claim-tenure transaction, people-claim/tenure transaction, tenure-claim/tenure transaction, and supporting document-claim/tenure transaction.

The importance of capturing these details is to provide rich descriptions of the different elements of a scenario and to provide a basis for data mining and social network analysis techniques. Due to the schema-less design model of the TTN database, it is both adaptable and able to account for the flexibility of capturing tenure information in dynamic situations, specifically conflict and post-conflict situations. Unlike a relational database which captures information in a predefined schema, the TTN database is schema-less. As a result, it is not limited in its ability to capture unstructured tenure information. The TTN database assists stakeholders in capturing complex tenure information on the ground regardless of its type, structure, and complexity in conflict or post-conflict situations. In turn, the social matrix can be further investigated and based on the information provided, hidden relationships can be extracted. Contradictions between elements of different captured information could indicate fraud and allow for its detection. In all, the flexibility of the system will enable stakeholders to capture any unforeseen situations on the ground and assist them in supporting their ability to mediate in conflict and post-conflict situations, as information integrity is not lost.

5.4.2 Supporting data mining and social network analysis techniques

This section builds on section 5.4.1. It describes and analyses the results of data mining and social network analysis techniques from the entered tenure information. More specifically, this section tests the TTN database for its ability to reveal hidden tenure relationships and to investigate the social matrix from the captured tenure information. Further details from the tests for the Palestinian and Somaliland scenarios are covered in Appendices A.5.2 and B.4.2, respectively. The results of the tests show that the TTN database is able to automatically reveal the hidden tenure relationships and investigate the social matrix. For example, the TTN database revealed significant hidden tenure relationships within the two tenure scenarios (see A.5.2 and B.4.2). These hidden relationships may be crucial for stakeholders to understand when discussing tenure claims, specifically inheritance claims between different parties. In addition, the data mining techniques provided additional information about a tenure object, showing overlapping and/or conflicting interests based on different descriptions provided in previous tenure claims and/or transactions.

For the Palestinian and Somaliland scenarios, data mining and social network analysis techniques extracted valuable information that was not described before. Appendices A.5.2 and B.4.2 show and discuss salient information that had been extracted about the respective scenarios for Palestine and Somaliland. Based on the results described in A.5.2 and B.4.2, data mining and social network analysis techniques provided significant information that never-before illustrated and is crucial to stakeholders to consider in order to settle a conflict. For example, over time, land can be inherited by multiple individuals. As the family names and/or clan names of inheritors may not stay the same, this complicates stakeholders' abilities to trace a parcel of land back its origins and investigate the possible relationships among the parties of the dispute (see Appendix B.4.2). However, via data mining and social network analysis techniques, stakeholders may be able to determine when the original land was divided and among whom, for example along maternal lineages.

The results show the TTN database is able to simplify the complexity of tenure information down to its most crucial elements. This is important because land tenure information in conflict and post-conflict situations consists of different types of tenure information and relationships. Thus, one key attribute of a viable system is that it is able to extract relevant information (*e.g.* social patterns) and make sense of it through data mining and social network analysis techniques (*e.g.* classification) (see Appendices A.5 and B.4). The TTN database is able to integrate different tenure elements and extract hidden tenure information and relationships due to the schema-less model of the TTN database and the integrated data mining and social network analysis techniques that make use of the Triple Store ontology languages. Moreover, the integrated data mining and social network analysis techniques assist in fraud detection processes by inferring any possible contradictions between the different items of the captured tenure information.

5.4.3 Describing tenure information

This section synthesizes sections 5.4.1 and 5.4.2 by testing the TTN database's ability to describe the Palestinian and Somaliland tenure information. This function allows the TTN to provide rich descriptions about the captured tenure information, marking a crucial distinction between TTN and other LTISs, specifically TTS. In this context, rich descriptions include the captured tenure information (see section 5.4.1) and the information resulting from data mining and social network analysis techniques (see section 5.4.2). Further details from the tests for the Palestinian and Somaliland scenarios are covered in Appendices A.5.1 and B.4.1, respectively. The test results show that the TTN database is able to provide clear and rich descriptions about the captured tenure objects and their complex relationships.

The TTN database describes two forms of tenure information. The first one is a unidirectional graph network (see Appendices A.5.1 and B.4.1 for the Palestinian and Somaliland scenarios, respectively). The second is a list of descriptions about each highlighted tenure element, broken down into three attributes that consists of a subject, a predicate, and an object (see Appendix A.5.2, figure A.8, Property Assertions). The subject is the source node; the object is the destination node; and the predicate is the verb that links the relationships between the subject and the object nodes. For example, as shown in figure A.8 in Appendix A.5.2, Yousef *hasSibling* Omar. Yousef is the subject; Omar is the object; and *hasSibling* is the predicate that describes the relationship between Yousef and Omar. The TTN database automatically categorized the captured tenure information among appropriate classes/subclasses based on their established relationships. For example, assume *A owns B* was entered. Automatically, the TTN database would classify *A* as a Tenant and *B* as a tenure element because the TTN database defines this type of relationship. All the tenure relationships in the TTN database are defined in a way that makes the TTN database capable of automatically classifying and distributing tenure elements among the defined classes. For the Palestinian scenario, see figure A.5 in Appendix A.5.1. For the Somaliland scenario, see figure B.3 in Appendix B.4.1). According to the established relationships among individuals, the TTN database automatically distributes the captured individuals among different classes to provide more information, beyond what has been entered in the system. Therefore, the TTN database describes each captured tenure element with its possible, associated relationships in different tenure contexts (see Appendices A.5 and B.4 for Palestine and Somaliland, respectively). Moreover, the TTN database is able to simplify complex tenure relationships by illustrating the captured tenure information in the mode of a unidirectional graph network.

In sum, the TTN database is able to describe tenure information flexibly by providing rich descriptions of tenure objects and relationships. The TTN graph network can be visualized in different ways to represent tenure information. For instance, the TTN database is able to visualize tenure relationships in hierarchal structure modes (*e.g.* Tree-Vertical structure, Tree-Horizontal structure, Vertical Directed structure, Horizontal-Directed structure) which help stakeholders to understand tenure relationships involved within an inheritance tenure claim (see figure A.6 in Appendix A.5.1). Also, it visualizes tenure information in a star (*e.g.* Radial) mode, which creates a clear visual of the stakeholders' relationships to a selected tenure object (see figures B.4 and B.5 in Appendix B.4.1). The different ways of visualizing tenure information support the TTN database's flexibility in describing tenure information and further enables stakeholders to trace inheritance patterns, and to focus on the core elements of a network in order to investigate specific claims and relationships.

In sum, based on the tests on simulated data, the TTN database can be applied to resolve land despites/claims among individuals by supporting social negotiation processes carried out by stakeholders. It supports these negotiations by providing stakeholders with rich descriptions about a tenure claims to support their decision-making. The data mining and social network analysis techniques of the TTN database can be used to reveal hidden tenure relationships that would otherwise not be readily available; infer illogical tenure relationships, which is useful in detecting fraud patterns; simplify complex tenure relationships; integrate different capture tenure elements (data) and generate (extract) potentially useful tenure information; and automatically investigate and visualize the social matrix. Subsequently, these techniques can provide more information about the roles of different individuals in inheritance disputes, show numerous changes in claims and land transactions, and provide a greater perspective on the interests of different parties. All of these features of a TTN database support negotiation processes carried out by stakeholders to bridge the gap between *de facto* and *de jure* in conflict and post-conflict situations, and in time can aid in stabilizing uncertain situations (see chapter three, section 3.2).

5.4.4 Limitations of the TTN database test and TTN database

This section illustrates the limitations of the TTN database test and the TTN database itself. The following list documents the test limitations:

- This test was limited to examining the TTN database functions only (see section 5.3).
- The test was limited to two land tenure scenarios, which means that the test did not examine all the nodes and links that had been programmed into the TTN database by the author. It was limited to the relationships and tenure elements mentioned in the two simulated tenure scenarios.
- The TTN database was not tested through a completed TTN system, instead it was developed through the Protégé software, which is not a LTIS. Therefore, this process is merely the initial test and should be repeated for field testing after the completion of the different components of the TTN application (*e.g.* GUI).
- The TTN database was tested by the author only, because it can be difficult for people who have no experience with Protégé to use it as a testing tool.

TTN database limitations:

- TTN is limited by how the designer sets up the system.
- The TTN database classifies incorrect information under the built-in *Nothing* class. This class collects unknown and inaccurate tenure relationships, those that contradict with defined tenure objects and relationships, and describes them as illogical

relationships in the TTN database. An example of inaccurate information that the TTN database classifies as an illogical relationship is, “land object A owns land object B.” The TTN database itself does not indicate how errors can be corrected. This can be addressed by developing a completed TTN system supported by different GUIs that can validate different types of entered information.

- It takes a long period of time to complete the process of describing hidden tenure information using a computer with Microsoft Windows 10 containing 4 Giga Byte (GB) memory and a Core i7 3.4GHz processor. However, a better performing computer processor and increased memory can reduce the amount of time for the system to display results.
- The TTN database is not ready for application in the field because it is not yet supported with graphical user interfaces. Field testing is necessary to further refine the database and data mining and social network analysis techniques.

5.5. Similarities and differences between the TTN database and TTS

To illustrate the similarities and the differences between the TTN database and TTS, the author installed the TTS database and entered tenure information from the two scenarios. After entering the tenure information into the TTS database, the author examined the similarities and differences between the TTS and TTN.

Table 5.1. TTN and TTS similarities and differences

Criteria		TTN	TTS
Capturing tenure information		Yes	Yes
Supporting data mining and social network analysis techniques		Yes	No
Describing tenure information	Asymmetric relationships	Yes	No
	Symmetric relationships	Yes	Yes

As shown in table 5.1, TTN and TTS were able to capture details about different tenure objects. TTS sufficiently described symmetric relationships (bidirectional) relationships (*e.g.* sibling), whereas TTN was able to provide a more detailed and flexible description of symmetric relationships. TTS described relationships in a relational table, while TTN described relationships as a unidirectional graph network, which clearly showed the connections between different tenure elements.

With regards to asymmetric relationships, TTS misrepresented them (see Appendix D), while TTN did not. Asymmetric relationships are directed and can only be read in one way. Based on the way that the TTS is configured, TTS may be limited in providing a comprehensive description of asymmetric (unidirectional) relationships (*e.g.* mother, father, uncle, and part of) in certain situations due to the many-to-many relation model that was used to design the TTS database. A database with a many-to-many relation model will become increasingly complex over time (Song et al. 2011), which can lead to the misrepresentation of asymmetric relationships. This type of relationship is significant, especially in inheritance disputes. The TTN database is able to describe different types of tenure relationships, visualizing them in the form of unidirectional graph network. Moreover, it is able to provide rich descriptions, beyond what has been captured, because the TTN database is integrated with data mining and social network analysis techniques. While the TTN database can infer information by extracting and then analysing it, the available LTIS cannot, TTS being an example, since their database designs are not integrated with data mining and social network analysis tools.

As data mining and social networking analysis techniques, which are significant for describing ambiguous or implicit relationships, were not considered as built-in tools in the TTS database, TTS is limited in inferring and revealing the ambiguous relationships based on the entered data. For example, if two persons have the same mother and father, TTS cannot infer that these two individuals are siblings. TTS is limited to describing the captured relationships, which were entered by the system operator. As shown in figure 5.2, TTS describes captured tenure information, while TTN describes captured information and all the possible hidden (implicit) tenure information among the captured (explicit) ones. Therefore, in the context of the two case data sets that were tested, the TTN is more flexible in describing tenure information than the TTS.

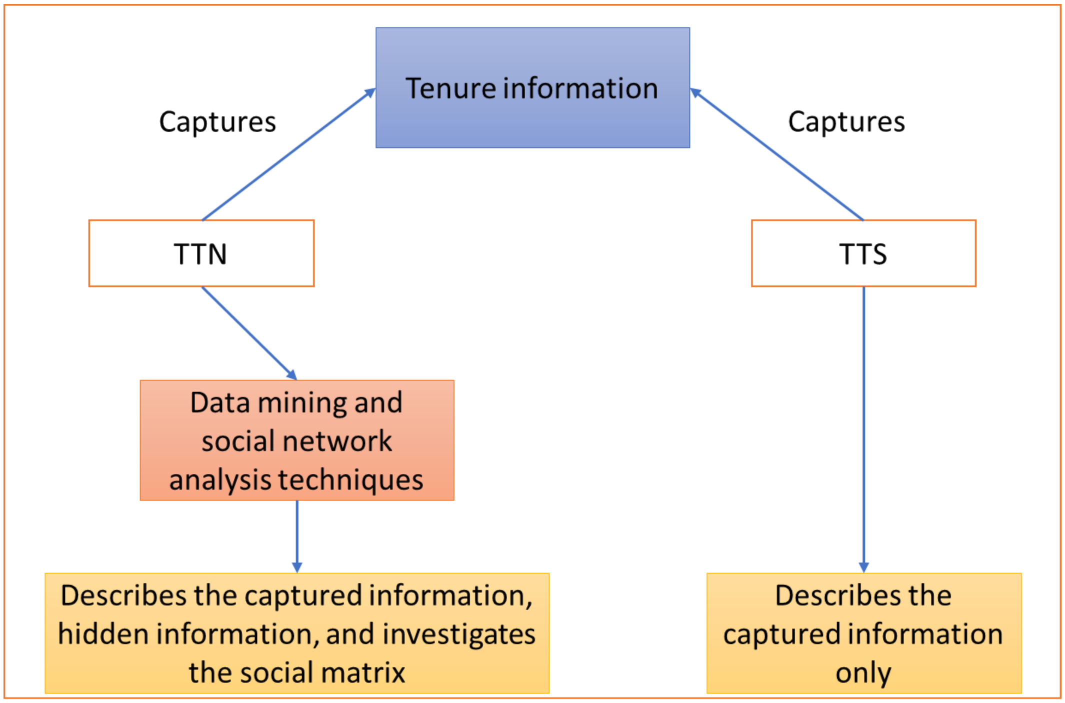

Figure 5.2. Describing tenure information using TTN and TTS

Compared to TTS, TTN offers more flexibility in describing complex land tenure relationships in conflict and post-conflict situations, as it supports data mining and social network analysis techniques that investigate the social matrix in order to provide rich descriptions about the captured tenure information. Therefore, in conflict and post-conflict situations, TTN is more effective than TTS in representing complex tenure relationships.

5.6. Relevance to research

The contents of this chapter contribute to the primary objective of the research (see chapter one, section 1.3.1) by testing the TTN database prototype based on the methodology described in chapter four. Protégé, as an open source software, was used as a platform for achieving the test. The test was achieved using two simulated land tenure scenarios for conflict and post-conflict situations. The TTN database prototype was evaluated based on the test results. It was determined that the TTN database meets its functional requirements. It was argued that TTN provides a better design solution to supporting tenure security in conflict and post-conflict situations, as it is capable of capturing and describing tenure information flexibly and able to infer and reveal hidden relationships through data mining and social network analysis techniques. The test illustrated that the database is adaptable and flexible which means that with field testing, and further refinements, it can be used to support tenure security in conflict and post-conflict situations.

5.7. Conclusion

This chapter examined the functions of the TTN database prototype. The purpose of the test is to determine if the TTN database is able to capture complex tenure information, support data mining and social network analysis techniques, and describe tenure information in a flexible manner. Two real-world simulated scenarios for conflict and post-conflict situations were used to achieve the test. The TTN database test and results were shown and discussed in sections 5.3 and 5.4. Further test results and discussion are covered in Appendices A.5 and B.4 for Palestine and Somaliland, respectively. The results prove that the TTN database meets its functions. The TTN database was able to capture complex tenure information and describe the captured information in a flexible and rich manner. A rich description included the captured tenure information, as well as possible hidden relationships, as the TTN database was able to investigate the social matrix of the captured information. To illustrate what the database has to offer, the author tested and compared another database to the TTN. The tenure information from the two simulated scenarios were used to test TTS. In section 5.5, the similarities and differences were discussed. The author argued that the TTN database provides a better design solution for capturing and describing complex tenure relationships in conflict and post-conflict situations.

This chapter has contributed to the achievement of the main objective of this thesis by discussing and analysing the outcomes of the TTN database test. It elaborated on the third and fourth components of the TTN database design theory described in chapter three, section 3.3 by detailing and testing the functions of the TTN database. The results of the test show that the TTN database achieves its objective in supporting tenure security in conflict and post-conflict situations, which is described in the first component of the TTN database design theory framework (see chapter three, section 3.3). The next chapter describes the conclusion of this research.

Chapter Six: Conclusion and Future Work

6.1. Introduction

This chapter concludes the thesis. It summarizes the contents of the thesis and it illustrates how each chapter contributed to the research objectives. Finally, it describes the key findings of this work and its contribution to knowledge. The TTN's limitations are highlighted and recommendations for future work are made. The topics are organized in the following order: (i) conclusions; (ii) limitations and (iii) future work.

This research argued that developing an adaptive schema-less graph network database design model provides the flexibility to capture and describe complex tenure relationships in conflict and post-conflict situations. A key feature of the TTN database design is the built-in data mining and social network analysis techniques. Using two real-world simulated scenarios i.e., Palestine and Somaliland, as illustrative cases, this feature was shown to improve the database's flexibility in describing complex tenure relationships by revealing hidden tenure information, visualizing tenure relationships as a unidirectional graph network, and investigating the social matrix automatically. The illustrative cases were based on lived experience, the literature review and correspondence with the study's supervisor.

Chapter one discussed the study's background, detailed the conflict and post-conflict context and problem, listed the objectives, introduced the questions this study sought to answer, and provided an overview of the research methodology. Chapter two described the first part of the literature review on land administration, land tenure, and land tenure information systems in conflict and post-conflict situations. It defined the key terms in this research and explored land tenure security in conflict and post-conflict situations. The chapter concluded by identifying the existing gaps and limitations of the available LTISs for conflict and post-conflict situations. Chapter three covered the second part of the literature review. It described the Conflict and Post-

Conflict Land Tenure Ladder hypothesis, applied the Gregor and Jones' (2007) Information System design theory framework to express the components of the TTN database design in a theoretical manner, and reviewed different database systems for the purpose of finding the most suitable database system to use for the design of the TTN database. The chapter concluded by identifying the Triple Store database system as the most suitable one to use for the development of a TTN database prototype as it was able to meet the identified functional requirements for conflict and post-conflict situations. Chapter four described the methodology used to develop the TTN database prototype. It detailed the TTN database development method and described its evaluation criteria. The chapter concluded by evaluating the TTN database design against the desired functional requirements in conflict and post-conflict situations. Chapter five tested the TTN database prototype in conflict and post-conflict situations using two illustrative real-world cases i.e., Somaliland and Palestine. The purpose of the test was to examine the system's functionality and determine its limitations. In addition, the chapter compared the TTN database with other available LTISs to illustrate similarities and differences in capturing and describing tenure information, and supporting data mining and social network analysis techniques. The next section discusses and analyses the study's key findings and conclusion.

6.2. Conclusions

This section presents the conclusion of this study by discussing the key finding as they relate to the research objectives in section 1.3. Objectives *a* and *b* were addressed in the literature review of this study. This section will specifically address the primary objective, and specific objectives *c* and *d*.

Specific objective c: *develop a functional TTN database prototype that supports data mining and social network analysis techniques automatically using the TTN database methodology.*

To achieve this objective, the Spiral software development life cycle model was adapted in the development methodology of the TTN database. The TTN database methodology consisted of three stages, each with different methods and activities. In Stage 1, the pre-design stage, land tenure data was analyzed to provide an understanding of the key land tenure objects and relationships in conflict and post-conflict situations. Land tenure data analysis provided an understanding of the key land tenure elements/objects/entities (*e.g.* clans, sub-clans, and families) and relationships (*e.g.* part-of, has-own, owns, inherited) that existed within specific conflict and post-conflict areas, Somaliland and Palestine. Next, the key features of conflict and post-conflict situations (complexity, dynamism, and unpredictability) that influenced land tenure elements/objects/entities and relationships were highlighted from the literature review, the author's lived experience, and data obtained from the author's supervisor. The activities conducted in Stage 1 assisted in identifying the requirements needed for the system. The combination of the two activities in the pre-design stage enabled the identification of the desirable system’s functional requirements for conflict and post-conflict situations, which were expressed in the form of the TTN database system propositions. It is on the basis of the design propositions that the TTN database design was initiated.

Stage 2 built upon Stage 1 by using the objects, relationships, and features of conflict and post-conflict situations to determine the desired features of the TTN database. Stage 2 focused on designing and developing the database. To achieve the primary objective of this study, the Triple Store database system was selected to develop the TTN database system. The identified tenure elements/objects/entities and relationships in Stage 1 were programmed into the database as triples that consisted of nodes and unidirectional links (relationships). Since data mining and social network analysis techniques were identified as desirable system requirements, Triple Store ontology languages were used to integrate automatic data mining and social network analysis techniques into the TTN database prototype. The outcome of this stage was a TTN database prototype that met the pre-defined functional requirements for conflict and post-conflict situations as per the system development evaluation. However, the resulting TTN database system does not include a GUI, which is necessary for onsite implementation.

Finally in Stage 3, the TTN database prototype was tested using two simulated illustrative scenarios: Gaza Strip in Palestine, a conflict situation, and Somaliland, a post-conflict situation. Protégé, an open source software, was used in place of GUI. The purpose of this experimental test was to examine the TTN database functionalities in conflict and post-conflict situations, identify aspects of the TTN database design that are in need of further improvement, and compare the system to other available LTISs in conflict and post-conflict situations.

The methodology described the stages followed for the development of an adaptive schema-less graph network TTN database for conflict and post-conflict situations. The developed TTN database methodology is appropriate for the purpose of addressing the primary research objective; it is a bottom-up approach that enabled the developer to better understand the conflict and post-conflict contexts, which were necessary in identifying the desired functional requirements that inform and are key to the TTN database system design. Moreover, the methodology supports an iterative design process that enables system refinement as new needs develop on the ground for conflict and post-conflict situations.

After the TTN database prototype was developed, two illustrative cases were used to test the database. Chapter five focused on achieving specific objective d through the testing of the prototype.

Specific objective *d*: *test the functionality of the TTN database prototype including the automatic support of data mining and social network analysis techniques using two simulated tenure scenarios, one for conflict situations, and one for post-conflict situations.*

Gaza Strip in Palestine and Somaliland were the two illustrative cases used to test the TTN database prototype. The Protégé software was used in place of a GUI. In addition, the Protégé software was chosen for the test as it is able to compile the Triple Store database and its ontology languages. The test focused only on the desired functionalities of the TTN database prototype, which consisted of entering tenure information, supporting data mining and social network analysis techniques, and describing tenure information. The tests for each function are further elaborated upon below.

- Entering tenure information:

This test determined if the TTN database prototype was able to capture complex tenure information in conflict and post-conflict situations. To test this function, tenure information was selected and entered from the data. Four main classes/nodes of the TTN database prototype were used to capture tenure information: Person/tenant; Tenure transaction and/or claim; Tenure object; and Supporting documents. The following main classes were used to enter tenure information:

    - *Person/tenant*: in this node, persons were classified based on their role(s) in the scenario and their personal information was added.
    - *Tenure transaction and/or claim*: in this node, a claim and relevant tenure transaction(s) were captured and classified based on their type (*e.g.* inheritance).
    - *Tenure object*: in this node, a tenure object is classified based on its type captured (*e.g.* land and/or development).

- *Supporting documents*: in this node, different types of evidence were captured (*e.g.* pictures).

The four main classes provided a guideline for selecting relevant tenure data that was to be entered into the TTN database. The two scenarios were entered separately using the extracted tenure data from each case. The importance of the above to entering tenure information was to represent different tenure relationships in land tenure disputes, and to determine if data integrity was lost through the misrepresentation and/or omission of relationships and/or relevant tenure elements. The test results indicate that data integrity was not affected when the data was entered into the database, which means that the database was able to adequately capture the complexity of the two simulated illustrative cases for conflict and post-conflict situations.

- Supporting data mining and social network analysis techniques:

This test determined if the TTN database prototype was able to support data mining and social network analysis techniques, which were used to infer of hidden tenure information, classify tenure data, and investigate of tenure network based on the entered tenure data. The Triple Store database system was used to design a schema-less unidirectional graph network database, which enabled the TTN database to support data mining and social network analysis techniques. The system is made up of nodes and unidirectional links (relationships), which form the graph network framework that supported social network analysis techniques. The integration of the Triple Store ontology languages within the TTN database design enabled the prototype to support data mining techniques, which were used to infer and classify hidden tenure information. These ontology languages differentiated and defined the TTN database's nodes and relationships. This critical support feature, the integration of Triple Store ontology languages in the graph network database was what enabled automatic data mining and social network analysis techniques, and this differentiates the TTN database system from the available LTISs for conflict and post-conflict situations. This test shows that the graph network Triple Store database system integrated with its ontology languages, RDF, RDFS, and OWL, can be used to successfully develop a schema-less database that automatically supports data mining and social networking analysis techniques. This feature is significant in conflict and post-conflict situations because it provides the basis upon which the flexibility of the TTN database can be enhanced to infer, classify, and describe land tenure information in dynamic conflict and post-conflict situations. In addition, the schema-less model of the TTN database allows the TTN database to be updated easily without having to reconfigure the whole design and/or distort the entered data.

- Describing tenure information:

This test determined the TTN database's ability to describe the entered and hidden tenure data, and visualise data in the form of a unidirectional graph network. The TTN database was able to describe and visualize the entered tenure data and hidden information in the form of asymmetric tenure relationships, as the TTN database relationship design consisted of defined source and destination nodes for specific relational links. The representation of asymmetric relationships is important in conflict and post-conflict situations because it helps to clearly delineate complex tenure relationships, thus avoiding the mischaracterisation of tenure relationships and/or people involved. An example of how the database prototype presents asymmetric tenure relationships is shown in Appendix D. The misrepresentation of asymmetric relationships is a common limitation of existing LTISs for conflict and post-conflict situations (*e.g.* TTS). This rich description of tenure information simplifies the complex web of tenure interests in conflict and post-conflict situations, which in turn may enable better understanding and inform processes targeted at improving conflict and post-conflict situations.

The TTN database prototype was able to visualize tenure information (the entered and the inferred tenure information) as a unidirectional graph network. In this network, tenure objects are represented as nodes, while the unidirectional links between represent different tenure relationships. Each link and node is able to flexibly describe an aspect of land tenure data in a schema-less model, wherein existing data does not need to be modified when new information is added. Therefore, a graph network database can be used to help develop a robust LTIS database that is not hampered or constrained by the challenges of the many-to-many relationships characteristic of a relational database system. This enhances the TTN database's adaptability in conflict and post-conflict situations because the graph network can change to represent the tenure practices on the ground. The graph network visualization of tenure information goes behind mere text description of the existing tenure relationships, as it aids in illustrating the extent of which tenure relationships have spread, which may enable stakeholders to trace the web of tenure relationships on the ground. The graph network visualization of the TTN database prototype may also assist in identifying centrality within land tenure relationships in conflict and post-conflict situations. This is important as it may help in understanding how tenure relationships are structured in these contexts.

These tests show that the TTN database prototype met the desired functional requirements. Specifically, the prototype showed that the different elements of the system on their own are able to meet their desired functional requirements. However, it is important that these elements are combined in a system with a schema-less unidirectional graph network to enhance data processing efficiency, reducing the cumbersomeness of preparing, exporting, and importing data from one system to another. The achievement of the specific objectives *c* and *d* led to the fulfilment of the primary research objective.

Primary objective: *to design and develop a schema-less graph network LTIS database prototype supported with data mining and social network analysis techniques that can be applied to conflict and post-conflict situations to improve land tenure security. This prototype will be tested using open source software.*

The design and development of the TTN database prototype showed that it is possible to develop an adaptive and flexible schema-less graph network LTIS database for conflict and post-conflict situations. The use of a schema-less database design model to develop a TTN graph network database design integrated with the Triple Store ontology languages enabled the capturing, describing, and revealing of important tenure information in the illustrative cases without the misrepresentation of complex tenure relationships, specifically asymmetric relationships. In addition, the TTN database prototype was able to automatically mine, and reveal hidden tenure information within respective classes. The TTN graph network database prototype experimental test showed promising results, therefore, further onsite tests should be carried out.

6.2.1 Contribution to knowledge

6.2.1.1 Theoretical contribution

The TTN database prototype enlarges the area of knowledge about designing and developing a LTIS for conflict and post-conflict situations through the design and application of a schema-less graph network database design methodology. Based on the literature review, it appears to be the first time that a schema-less graph network LTIS database that is able to support and integrate automatic data mining and social network analysis techniques has been developed for land tenure administration in conflict and post-conflict situations. Applying a graph theory to design and develop a graph network LTIS database for conflict and post-conflict situations may improve the flexibility of capturing and describing tenure information and handling complex tenure relationships by modelling tenure relationships as a set of triples (nodes and unidirectional links). Using the Triple Store database to develop a LTIS database for conflict and post-conflict situations may result in a flexible LTIS database that maintains an acceptable degree of robustness. Also, the Triple Store database supports data mining and social network analysis techniques automatically through its ontology languages. Figure 6.1 shows the interrelationships between the different components of the TTN database. As shown in figure 6.1, OWL is based on RDFS which is based on RDF. The combination of the three ontology languages forms a Triple Store graph network database that is able to support a rudimentary form of data mining and social network analysis techniques automatically. RDF is used for modelling the TTN database triples in a schema-less way.

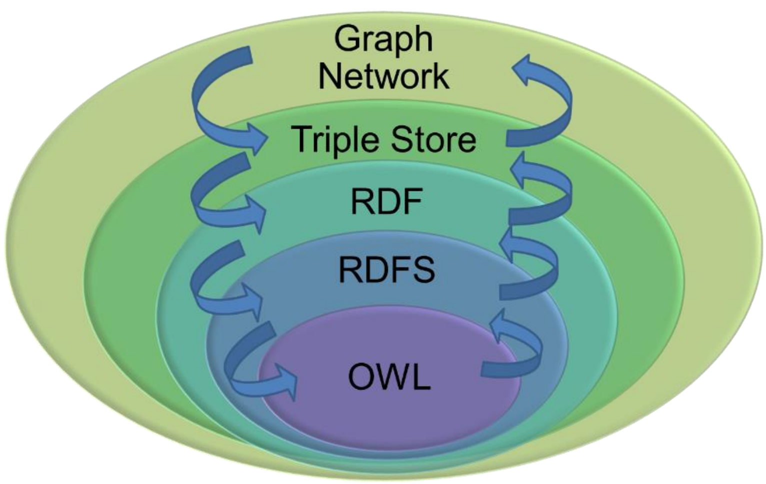

Figure 6.1. TTN Database Components

6.2.1.2 Empirical contribution

Based on the TTN database design and experimental results that were outlined in chapter five, it can be concluded that the application of the Triple Store database was suited for support the development of a LTIS database for conflict and post-conflict situations. Entities of the Triple Store database, more specifically the incorporation of 'triples' and the ability to perform semantic queries, allows the database to be both flexible enough to capture the variety of incoming datasets while maintaining a significant level of robustness in terms of internal data integrity (data integrity of existing and sorted data). This is further highlighted by the higher level applications of semantic queries and triples, specifically the development of schema-less graph network databases that enable relationships to be defined between objects through unidirectional links. These unidirectional links further aid in the flexibility of the database by allowing the database to be updated in “real time” or significantly faster than traditional relational databases. This is primarily due to the fact that relational databases incorporate schemas with many types of relationships (i.e. one-to-one, one-to-many, many-to-many, etc.) and in order to effectively update a relational database the developer must be cognizant of how an update will affect each of these various relational types both individually and inclusively. Therefore, the inclusion of graph-network data management techniques in LTIS databases supports a higher degree of tenure security in conflict and post-conflict situations.

The application of a bottom-up design approach and the Information System Design Theory improves the functionalities of a LTIS for conflict and post-conflict situations. The improvement of these functionalities may enable the LTIS to improve tenure security in conflict and post-conflict situations under enabling conditions.

6.3. Limitations

The TTN database is limited in its external design. The TTN database is not yet ready to be used in the field due to the fact that it requires GUIs. The integrated data mining and social network analysis are still in the initial stage of development as these tools are designed to reveal hidden relationships, classify tenure information, and investigate the social matrix. Regarding the integrated data mining and social network analysis techniques, the TTN database is not yet ready to meet all stakeholders’ requirements as the data mining and social network analysis techniques need to be further developed to specify and analyse particular relationships between clans-families, families-extended families, and people-media, for instance.

The TTN database is able to capture spatial information about tenure objects, but it is not yet ready to support spatial data analysis and processes due to the fact that it is not yet linked with an open source Geographic Information System (GIS) application.

6.2.2 Potential drawbacks

This section briefly details conditions under which the TTN database may not be effective. The TTN database is not recommended as a national registration system, nor should it be applied in a stable situation since the TTN database is mainly designed to handle unstructured and complex tenure relationships that are difficult to understand. Tenure disputes may exist in stable situations such as Canada, however, unstructured data is not as important because the structured data is enough to support tenure security.

The TTN database requires support from local level policies and institutional acceptance to be implemented in conflict and post-conflict situations. Also, training may be required to use the TTN database since it is not a standard database that users are familiar with.

6.4. Future work

This section suggests recommendations to further develop the current TTN database prototype. The author proposes three primary areas for future work.

First, this research focused solely on the development of the TTN database prototype. To be applied in a given context, the TTN database is in need of graphical user interfaces. Semantic web technologies, such as SESAME and Jena, can be used to develop graphical user interfaces for the TTN database. Designing a web based GUI for the prototype will make it more user friendly, and enable users to access the database remotely through a variety of platforms (*e.g.* iPad, computers, laptops, and cellular devices). Moreover, it will enable the onsite testing of the TTN database.

Based on the test results and the feedback of the TTN database operator(s), further investigations to guide future development can be undertaken (*e.g.* improving the TTN database design and/or data mining and social network analysis techniques) in order to enhance the effectiveness of the TTN performance in conflict and post-conflict situations.

Second, the integrated data mining and social network analysis techniques of the TTN database are still in the initial stage of development. Further development is recommended for these techniques in order to enable the TTN database to mine and analyse specific tenure relationships that are of interest (*e.g.* people-people, people-land, and clan-families). Furthermore, the integrated data mining technique of the TTN database can be developed to provide auto-face recognition. This is significant since the TTN database captures different types of media (*e.g.* pictures and tapped video) that describe different tenure relationships. Auto-face recognition would enable the TTN database to recognize different hidden relationships that may exist between people and media. These relationships may be useful for stakeholders to be considered to support their negotiation processes with people.

Lastly, the TTN database needs to be linked with any open source Graphical Information System (GIS). This feature enhances the TTN database's flexibility by visualizing spatial tenure information onto a map. Also, it enables the TTN database to support spatial operations that can be used for land administration purposes (*e.g.* land use planning). Linking the database to a GIS application would enable stakeholders to visualise spatial information, and generate maps to determine specific conflict areas that need to be addressed for land use planning purposes.

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Appendx A: Gaza Strip Case Study

A.1 Gaza Strip land tenure case study

Appendix A provides an overview of the simulated land tenure scenario for the Gaza Strip, a conflict situation. The motivation for choosing this region is described in section 1.6. This appendix discusses the methodology used to simulate the Gaza Strip scenario which was used to test the TTN database prototype's functionalities for a conflict situation. The author simulated a land tenure scenario for the Gaza Strip based on the literature review and the author's observations as an experienced local tenant in the area. Data used in the Gaza Strip scenario consists of primary and secondary data.

Appendix A includes diagrams from the TTN database that illustrate the test results from the entered Gaza Strip land tenure data. People-people, people-development, people-land, land-development, clan-sub-clan, land-land, and people-media relationships and informal and customary tenure agreements were entered and tested in the database. To capture the land tenure scenario, the following classes were used and tested: *Apartment*, *Building*, *CaseArea*, *CaseCountry*, *CaseID*, *CaseName*, *Claim*, *CourtName*, *House*, *LandObject*, *Merge*, *Person*, *ShariaLaw*, *StagesNumberBasedYear*, *XeerLaw*, and *YearStamp*. Descriptions for each class can be found in Appendix C.1.

The limitations of the Gaza Strip scenario are that the scenario is not real and biased by the author's background as a computer scientist and a Palestinian national. The scenario was developed for the specific objective of stabilizing land tenure information in the presence of conflict. For example, the scenario focuses on land disputes rather than technical land administration processes because this study focuses on the development of a land tenure information database with the goal of supporting tenure security in conflict and post-conflict situations.

The following subsections describe the terminology and the simulated scenario of the Gaza Strip. The author used pseudonyms in the simulated scenario.

A.2 Overview

This scenario provides tenure data to test the TTN database's functionalities for an ongoing conflict situation. The tenure data from the scenario provides an example of some of the multifaceted tenure relationships that may exist in ongoing conflict situations and serves as a sample tenure dispute that users of the TTN database may deal with. This illustrative case describes complex tenure relationships that are not easily identified and understood by stakeholders, as there are multiple interconnected networks and sub-networks of tenancy.

This section is organised as follows: (i) land tenure in Gaza; (ii) methodology for generalizing the Gaza Strip land tenure scenario; (iii) test results and analysis; and (iv) relevance.

A.3 Land tenure in Gaza

The next section provides background information about land tenure in the Gaza Strip. The complex history of Palestinian land laws and regulations in combination with the current Israeli occupation and deficient circumstances have contributed to an inefficient Land Tenure Information System (Ministry of Planning, 2008). The regulations in Palestine are a combination of laws and rules gathered from different historical eras, starting from the Islamic period (638 to 1516 CE), the Ottoman Empire (1516 to 1918 CE), the British mandate (1918 to 1948), to the Israeli occupation (1948 to present). As per the Oslo agreement between the Palestinian Liberation Organization (PLO) and Israeli government in 1995, the Palestinian Authority was established and given the control of a 6165 km^2 region. This area was then divided into two sub-areas: the Gaza strip (365 km^2), and the West Bank (5800 km^2) (Stewart and Martinich, 2013). Additionally, the Oslo agreement divided the West Bank into three areas (A, B, and C), each with different borders, security, administrative agreements, and authorities. This work will primarily focus on the Gaza strip. It is important to note that the Ottoman rule continues to have a significant influence on current land rules in Palestine. During the Ottoman rule, the land tenure and registration system was significantly changed by the implementation of certain ordinances which remain in effect today. One of the most significant ordinances was "Tapu." The Ottoman land code of 1858 (Tapu Law) classified Palestinian land into five categories (Dajani, 2005; Land Governance 2014; Simpson 1930; Pogrund, Salem, Scham, 2005; Tamim, 1995):

1. Mulk: land owned by an individual who has full ownership rights.
2. Miri: state-owned land utilized by individuals under specific conditions. The owners do not have the authority to sell the land.
3. Waqf: land governed by Islamic law and used for public benefits.
4. Metruke: public land assigned for infrastructure (*e.g.* roads). This type of land is not subject to sale or purchase.
5. Mewat: natural land that cannot be possessed or cultivated by any person (*e.g.* mountains, and forests).

Tapu is an official tenure title (in Arabic with an English summary) that secures tenure against threat, and is fully recognized and supported by the Palestinian Land Authority in the Gaza Strip (Palestinian Land Authority 2016). Tapu is a significant document for all of these different types of land, specifically Mulk, as most of the land disputes in the Gaza Strip, especially inheritance land disputes, are over Mulk. Owners of Mulk may apply for Tapu, but most of them choose not to in order to avoid expensive fees and the payment of taxes (Mikkonen and Corker 2012). In general, this type of land is inhabited by farmers and then families, who have occupied and cultivated the land for several decades.

In addition to the different types of land that were mentioned above, private and customary land practices are critical to understanding land tenure in Palestine. In many cases, the land is sold privately and inherited through a notary using a private conveyancing system. Without recording the transactions officially in the land registry offices, the notary drafts a land transaction agreement for each party (Mikkonen and Corker, 2012). The parties sign the agreement in front of the notary, and the notary keeps the deed in his archive. There is a governmental land registration office that records these tenure transactions, but most people choose not to register. Thus, most landholders use a form of private conveyancing and rely on the notary to keep the records secure and accurate.

It is important to describe the formal and informal land registrations in the Gaza Strip because the evidence that people produce to claim their land ownership may comprise both formal and informal documents. The author designed figures A.1 and A.2 to describe the official (formal) and the private (informal) land registration systems in the Gaza Strip, respectively. As shown in figure A.1, the official land registration is made up of the following steps (Mikkonen and Corker, 2012):

1. Declaration: the legal action of announcing a new registration process in newspapers.
2. Allegation: the claimant presents an official claim of ownership and presents the required evidence.
3. Demarcation: a land surveyor demarcates the land claimed.

4. Claim verification: the governmental institution determines a schedule for submitting the ownership claim of the owner to verify that no claims or disputes for the property exist.
5. Adjudication: the evidence is evaluated and potential disputes are resolved; then, parcels are adjudicated and interests are registered.
6. Appealing to High Court: this step is undertaken in the case of fraud. This is subject to appropriate Statute of Limitations (normally 6 years) (Mikkonen and Corker, 2012).

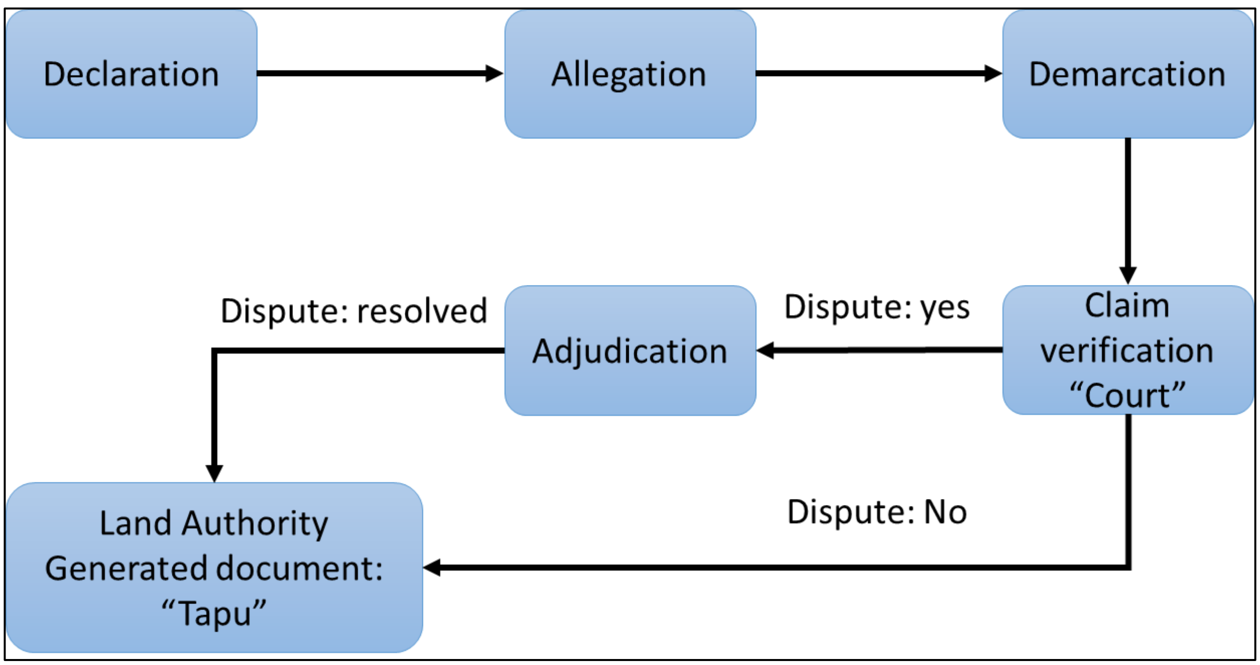

Figure A.1. Official land registration process

The tenant receives a "Tapu" document upon completion of the registration process. This Tapu document is considered by the government as the most well recognized claim of legal ownership. However, if such a document is not procured, then land claims will not be recognized by the government and the parties will need to go through a negotiation process to resolve the claim. The TTN database should capture this document (if it is available) as one of the supporting documents to describe tenure relationships in the Gaza Strip.

The private registration system procedure consists of several steps similar to the official registration procedure. Figure A.2 describes the steps of the private system. Firstly, the tenant must prove ownership of the property, which is subject to sale to the buyer, by presenting appropriate evidence (*e.g.* Tapu or notarized purchase contract). Secondly, a surveyor defines the boundaries of the property and plots this onto a map. Lastly, both parties (buyer and seller) use the surveying document to sign the tenure transaction agreement in front of a notary, and the notary archives the signed deed.

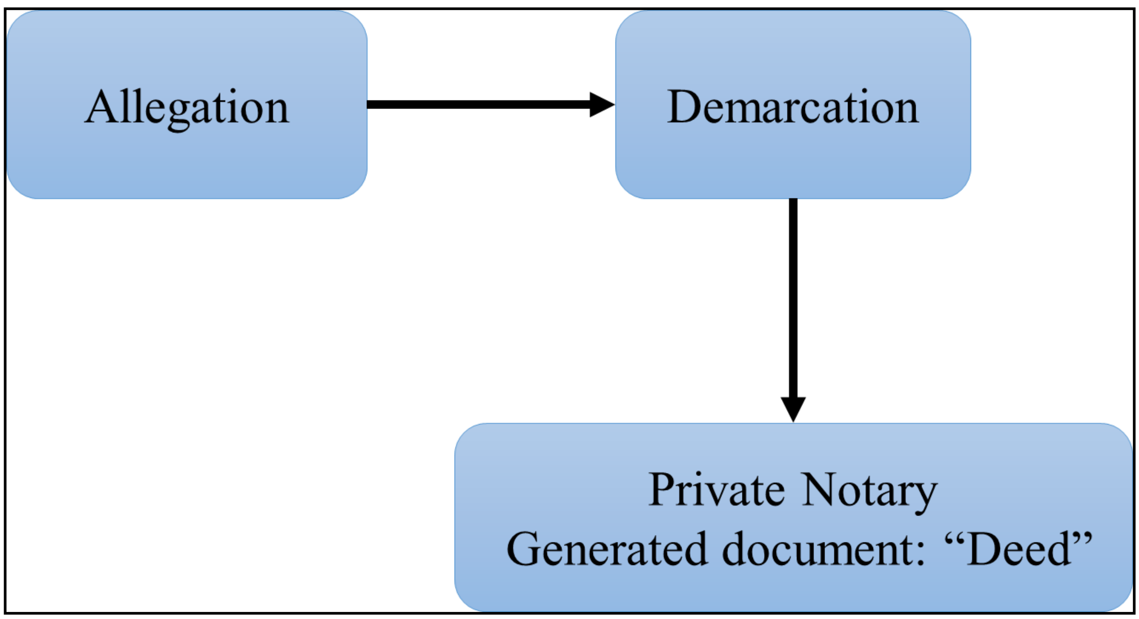

Figure A.2. Private land registration process

Generally, tenants in the Gaza Strip are classified into two groups: the first group describes tenants who choose to register their land; and the second group describes tenants who choose not to register their land objects. The first group is classified into two types: the first type contains tenants that choose to follow the private registration process; and the second type contains tenants that choose to follow the official registration process (Ministry of Planning 2008). Both are not equally recognized by government. People who follow the official registration process can access basic infrastructural services from the government such as water and electricity. The TTN database, as designed and tested in the experimental work, captures supporting documents generated from both registration systems to describe tenure relationships.

A.4 Methodology for generating the Gaza Strip land tenure scenario

This section describes a simulated land tenure scenario in the Gaza Strip. The scenario describes a multifaceted land dispute among family members and their next-door neighbour. This scenario was simulated in the following manner: The problem situation was identified; key elements of the problem situation (institutions, people, and relationships) were identified; interrelationships between key elements were determined; the tenure problem situation was determined; and finally, the tenure problem scenario was generated.

1. Identifying the problem situation:

Land tenure and property disputes in the Gaza Strip occur in the context of an ongoing conflict situation. This section describes land tenure in the Gaza Strip and the characteristics of the tenure conflict situation in this region.

To recap, the Gaza Strip area is 360 km^2 with one of the highest population densities in the world (Central Intelligence Agency 2016). More than 1.76 million people are living in this area (UNRWA 2014). In many cases in the Gaza Strip, land is sold privately and inherited through a notary using a private conveyancing system that makes use of customary agreements, and these transactions are not officially recorded in land registry offices (Mikkonen and Corker 2012; Koek et al. 2015). The government faces a significant challenge in assisting people to resolve land tenure disputes, as unofficial documents are not recognized by the government; instead, people have to resort to social negotiation processes. Approximately 70% of private lands in the Gaza Strip are not registered in the official records (Koak et al. 2015).

Due to the ongoing conflict situation between Israeli and Gazan fighters, there is massive home and property destruction in Gaza. For instance, the 2014 war between Israeli and Gazan fighters led to the destruction of approximately 16,000 houses and displaced more than 117,000 Palestinians (Koek, Arafat, and Clutterbuck 2015). The ongoing conflict situation complicates tenure disputes between people, as some take the opportunity to grab land, and establish informal and illegal settlements over unregistered properties. In the aftermath of these conflicts between Israeli and Gazan fighters, tenure conflicts occur between people over property and land boundaries. In addition, inheritance problems can exacerbate the challenges that are already present, as family members may argue over the amount of property claimed. Restitution processes are at a standstill due to land tenure conflicts between people who have lost their properties and the difficulty in identifying rightful landowners (Koek et al. 2015). The aforementioned challenges are considered in the TTN database design.

2. Determining the key elements of the problem situation:

Key elements of the problem situation consist of families, extended families, neighbors, supporting documents, courts (*Sharia* court, and/or governmental courts), customary laws, social negotiation processes by elders, tenure relationships, inheritance issues and tenure disputes between neighbours, and war. These elements are incorporated in the TTN database classes (see figure C.1 in appendix C.1).

Social structure in the Gaza Strip influences land tenure relationships. Gaza is a semi-nomadic society, in which the concepts of tribes, small clans, and families predominate. A tribe consists of several clans where each clan consists of many extended families. Each family has an elder that represents the family for different occasions. The association of the extended families is led by one person called *Mukhtar* (plural *Makhateer*); all these extended families are connected through a father that dates back to five or six generations (Landinfo 2008). For conflict resolution, *Makhateer* play a significant role for mediating and resolving different types of conflicts (*e.g.* blood conflict and tenure conflict) between families. They apply customary law influenced by religion and the rituals of the society to negotiate tenure disputes (Landinfo 2008).

Tenure disputes between neighbours and inheritance tenures dispute within a family are serious problems that may eventually lead to violence between families or family members in Gaza (Landinfo 2008; Koek et al. 2015). Between the years of 2009 and 2015, the ongoing conflict between Israeli and Gazan fighters in Palestine displaced a number of families. When the conflict ceases, people return to their homes to find their properties completely destroyed, and land boundaries unclear. Neighbours may disagree over property boundaries. As their land is unregistered, they face the challenge of proving their ownership and of determining the borders of their land (Koek, Arafat and Clutterbuck 2015).

When land conflicts arise, people prefer to appeal to whichever court will best support their claim (either *Sharia* and/or customary), or they go through social negotiation processes supported by *Makhateer*.

3. Determining and understanding the interrelationships among the different elements of the problem situation:

This section describes the interrelationships among different people and tenure elements in the Gaza Strip region. These tenure relationships are incorporated in the relationships found in the TTN database (see tables C.1 and C.2). One of the main interrelationships considered is the overlap of internal disputes and external disputes. In the context of this scenario, the TTN database focuses on a multifaceted overlapping tenure dispute consisting of internal disputes among family members, and external disputes between the whole family and their next-door neighbour.

The second interrelationship that is considered is the involvement of various mediators. Usually people who have inheritance issues go to *Sharia* court, which is influenced by Islamic law. People who are not satisfied with *Sharia* court may go through social negotiation processes. However, neighbours who have tenure conflict do not go to *Sharia* court. Typically, neighbours in dispute will undergo social negotiation processes that are mediated by elders to resolve tenure conflicts between parties. Each party of the conflict provides all of her/his supporting documents (informal and formal). Then, elders mediate and advise on the tenure conflict.

4. Describing the problem situation:

This section contextualizes the tenure scenario. The internal tenure dispute focuses on an inheritance problem among family members, while the external one focuses on the expansion of the internal conflict between the family members and their next-door neighbour. The father of an extended family passed away, and the tenure documents of the house and land disappeared. One of the family members claimed that the land was his, and the other members of the family have the right to share the house only (as inheritors). The claimant argued that the father bought the land with his (claimant) money.

Moreover, multiple wars occurred in the Gaza strip between the years of 2009 and 2014 and these wars destroyed many homes in different communities. This left a negative impact on land tenure security and brought many previous tenure disputes to the surface. The dispute was postponed, but after the destruction caused by these wars, the reconstruction of the property forced the family to address their dispute. This dispute needed to be addressed immediately before it worsened. The family chose to undergo the social negotiation process.

For the internal tenure dispute, the TTN database is designed to capture tenure objects (land and development); family members that are involved in the internal dispute; tenure relationships between the family members and the tenure objects; and the inheritance tenure claim. For the external tenure dispute, the TTN database is designed to capture the informal agreements between people, the amalgamation of different land objects (see figure A.4), the different interrelated tenure relationships that exist among land, people, and developments, and finally customary claim(s) between people.

5. Generating the simulated problem situation:

This section simulates a tenure dispute in the Gaza strip based on the material described in the above sections. The scenario took into consideration the recurring wars that displaced claimants, the inheritance problem that can be found within a family, the nature of informal agreements between people, and the challenge of unregistered properties. The scenario is described below.

An extended family known as the Ismail family was living in a house in the Gaza Strip. Using the terminology in Appendix C, Ismail and his wife Hend had three sons, Yousef, Omar and Khalid, and a daughter named Rasha. Ismail owned “Ismhouse” and the land object “IsmLandObj01”. Omar is exiled, and he lives in Dubai. Rasha is disabled (mute), and she lives in her father’s house. Khalid is a Palestinian prisoner in Israeli jails, but his small family (a wife, a son, and a daughter) live in Ismail’s home. In 2008, Ismail passed away and the tenure documents related to his land and house were destroyed. One of the heirs, Yousef, claimed that he was the owner of the land and that the rest of the heirs only shared the house with him. Yousef supported his claim with oral stories and unofficial documents. Contesting this, all the heirs except Yousef claim that the land and the house belonged to their father. Therefore, they argued that they had the right to share their father’s land and house fairly.

In 2009, a war broke out between Israel and Palestine. After the war, Yousef entered into an agreement with Hani, the next-door neighbor. According to the agreement, Hani would rebuild the ground floor up to 10m in height for Ismail's family on the land. In exchange, Hani has the right to build as many floors and units as he wishes on top of Ismail's floor. Consequently, the extended family is only permitted to live on the ground floor. The author created figures A.3 and A.4 to illustrate the property before and after the agreement between Hani and Yousef, respectively. All the inheritors except Yousef rejected this agreement. However, the agreement was applied and a new building was constructed over Hani's and Ismail's land objects. In 2014, a second war broke out that destroyed the building again. Now, Hani claims that he has the right to get a portion of Ismail's land since he once had a building over it. Currently, the conflict has been extended from within the family to also occurring between Ismail's family members and their neighbor, Hani. Thus, two different claims were submitted for this tenure conflict. An inheritance claim was submitted by Yousef's siblings to the *Sharia* court against Yousef. The second claim was a customary claim supported by social negotiation process over Ismail's land by Hani against Ismail's family.

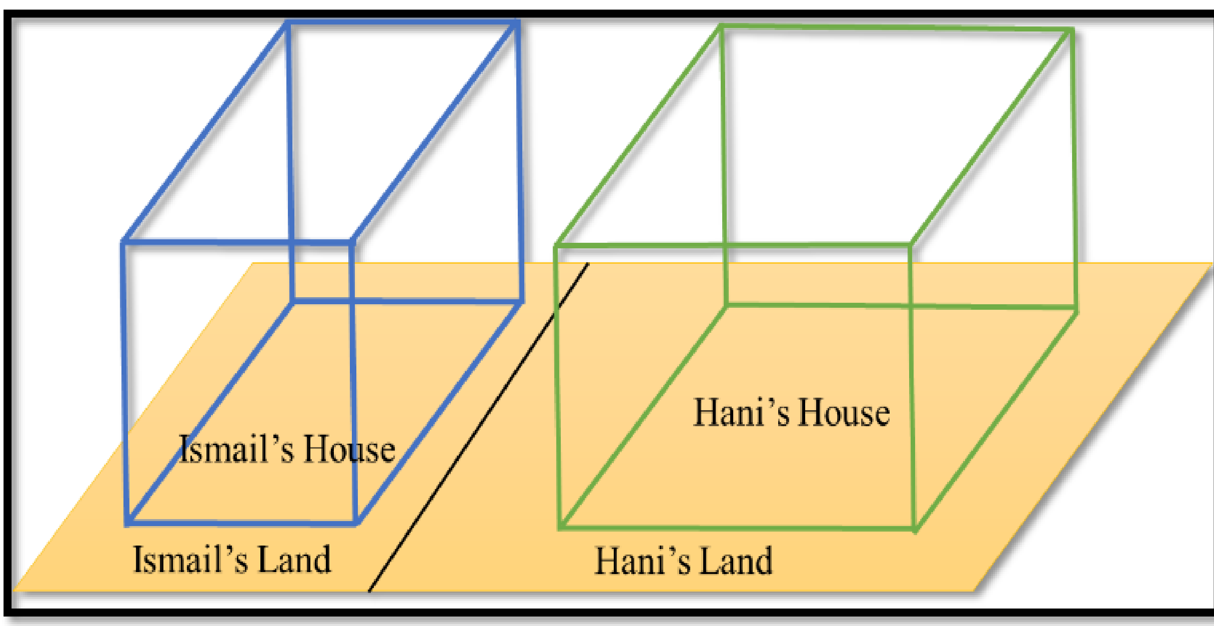

Figure A.3. Before the agreement between Hani and Yousef

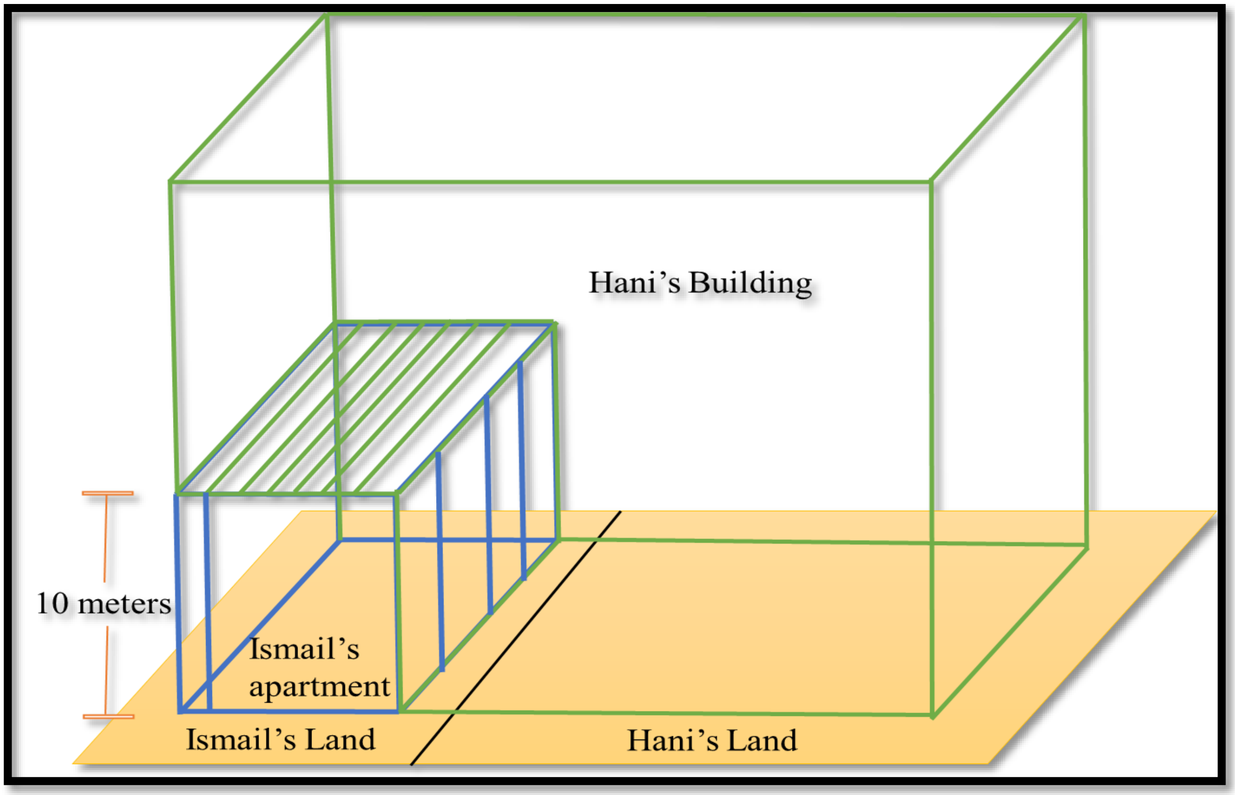

Figure A.4. After the agreement between Hani and Yousef

A.5 Test results and analysis

A.5.1. Capturing and describing tenure information

After capturing the tenure data from the scenario, the TTN database classified the captured data according to the defined TTN relationships. Data mining and social network analysis techniques were applied to provide rich descriptions about the captured information and to visualize this information as a unidirectional graph network. Further detail about supporting data mining and social network analysis is covered in section A.1.4.2.

This section focuses on the database's ability to capture and represent tenure information. The TTN database was able to automatically classify the captured tenure information among different classes/sub-classes (see figure A.5) based on their relationships. The benefits of this feature can be clearly shown after entering a large number of tenure disputes. Figure A.5 shows that this feature works by classifying the captured tenure information of the Palestinian case. One of its advantages is that it helps stakeholders to understand the structure of the society and the people's strategies in land disputes. For example, in inheritance disputes people can opt for different dispute resolution mechanisms (*e.g. Sharia* law, Secular law, State law, and *Xeer* law). In the captured scenario, figure A.5 shows that *Sharia* law is the most common dispute resolution mechanism. This information may help stakeholders identify the context within which tenure disputes occur and can be resolved. This may inform the development of practical strategies that may help in stabilizing conflict situations and support tenure security within the context.

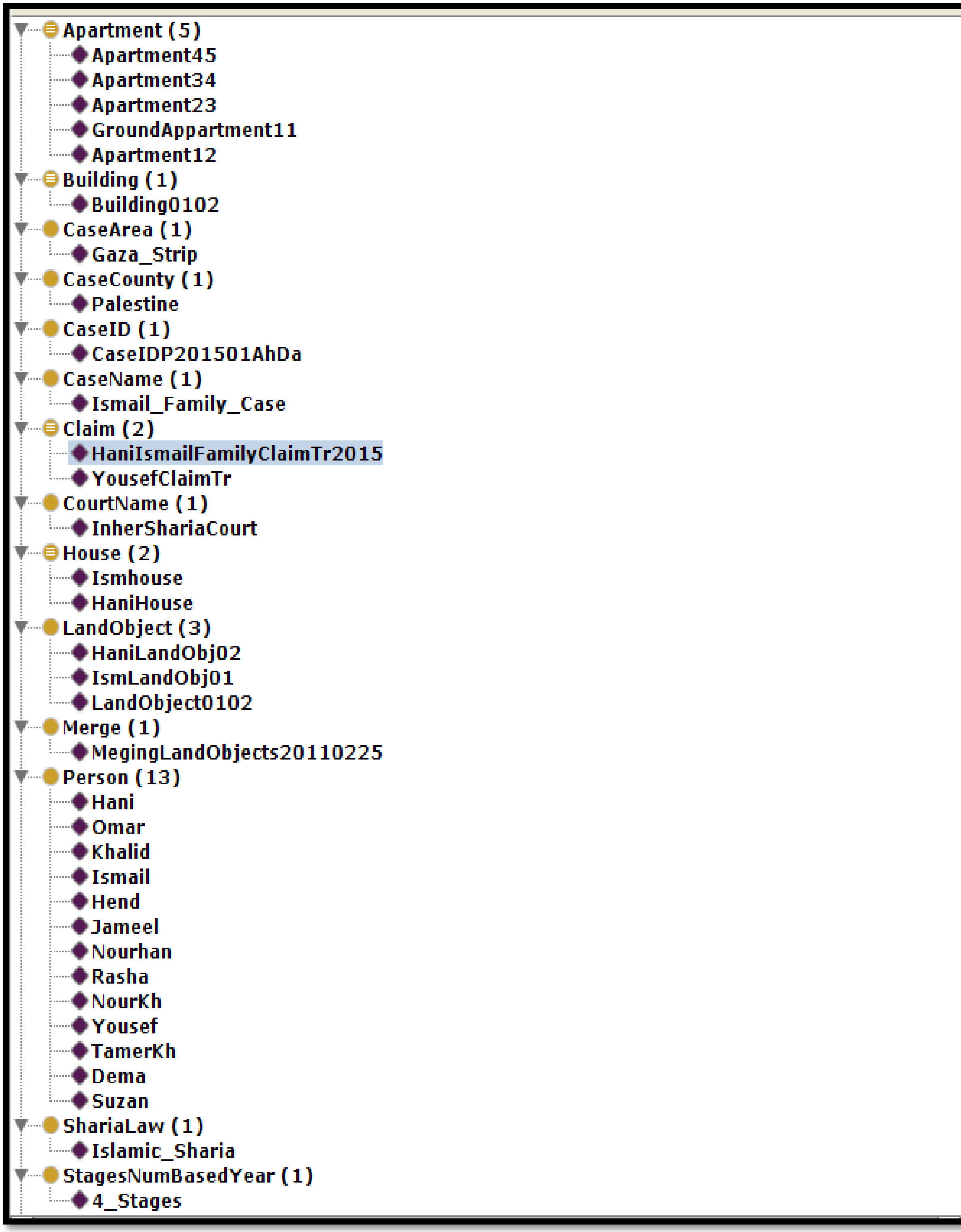

Figure A.5. Classifying Tenure Information - Palestinian Case

The TTN database is able to visualize complex tenure relationships in the form of a unidirectional graph network. As shown in figure A.6, the graph network can visualize the Gaza Strip case in the Horizontal Directed mode. Through this mode, complex disputes can be simplified. The internal dispute is sorted from the external disputes. The internal conflict is shown on the right half of figure A.6, illustrating the inheritance dispute over Ismail's land, "IsmLandObj01". On the left half of figure A.6, the external dispute between Ismail's family and their next-door neighbour is shown. The visualized network in the figure helps in determining the key person(s) that influenced the internal and external tenure disputes. For instance, in this scenario, Yousef had an influential role in the internal and external disputes so he is shown in the middle. The thick dashed-lines illustrate Yousef's connections to the internal and external disputes. This visualization mode may assist stakeholders in tracing internal and external conflicts to determine key individuals, irrespective of power, as well as other influences. Also, the visualized network in figure A.6 sorted the different components of the dispute to assist in understanding the dispute from the past to the present and from the present to the past. For example, users may understand the events of the dispute from the past to the present by examining the graph network in the figure from the right to the left, and vice versa for the present to the past. It may help to understand how individuals influenced the internal dispute such as Ismail and Yousef, while others influenced the external dispute such as Hani and Yousef. All the individuals, events, and land transactions/operations that influenced and changed the nature of the conflict are represented in the middle. For instance, the TTN shows the different stages of the conflict captured in the *YearStamp* class (see Appendix C, section C.1, class number 1.6)

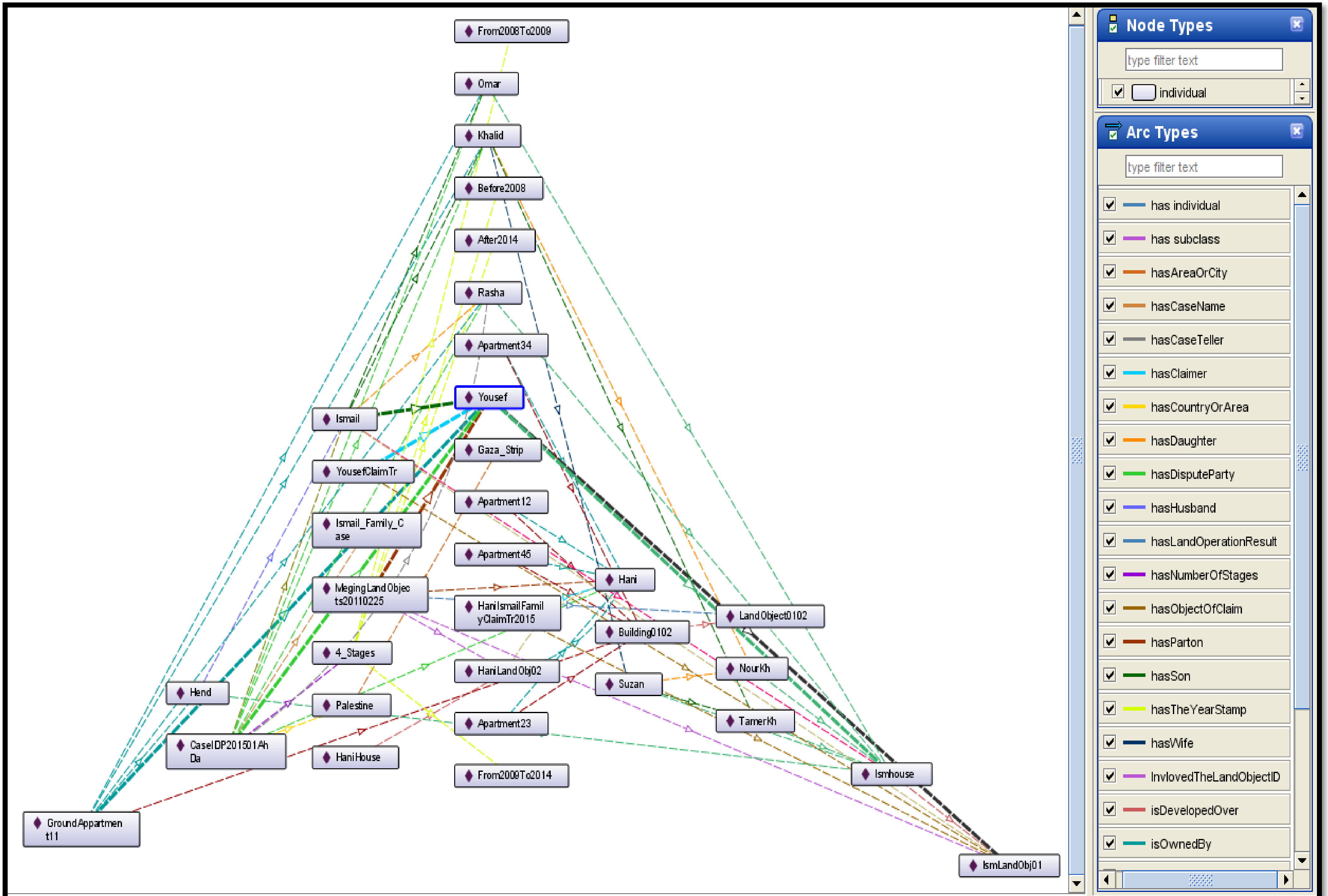

Figure A.6: Horizontal Directed Graph Network - Palestinian Case

Also, the TTN database illustrates how the conflict was extended from an internal conflict to one consisting of both internal and external conflicts (see section A.1.4). Figure A.7 shows the different stages of the conflict and external factors i.e. war that exacerbated the conflict situation (see figure A.6). Figure A.7 should be read from right to left in order to be consistent with figure A.6.

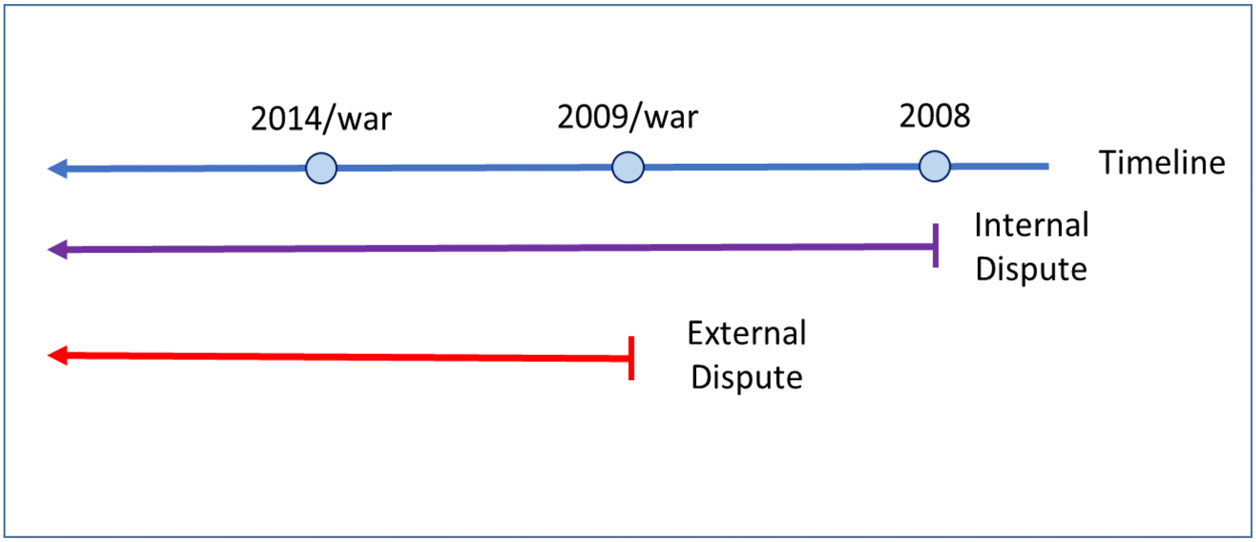

Figure A.7. The different stages of the internal and external tenure dispute - Palestinian Scenario

The above figure is a simplified representation of figure A.6. It is indicative of the fact that in ongoing conflict situations, external factors such as war may worsen the situation. The enabling condition that extended the dispute from internal to external is the war. In the above figure, the conflict situation became more complex after the 2009 war. The war provided an occasion for opportunistic actors (i.e. Yousef and Hani) to take advantage of the situation, further complicating the already existing land tenure problems on the ground.

A.5.2. Supporting data mining and social network analysis techniques

Due to the integrated data mining and social network analysis techniques, the TTN database provided rich descriptions about the tenure dispute, showing more than what was entered. These rich descriptions may help stakeholders to better understand and support social negotiation process as significant tenure relationships that were not seen or entered before are revealed. Figures A.8 and A.9 illustrate the extracted information about Yousef and Hani, respectively. As shown in figures A.8 and A.9, the extracted information about Yousef and Hani are highlighted in yellow. The non-yellow information is the entered tenure information. Figure A.8 shows that the integrated tools inferred the following: Yousef is an individual of the *Son* class, including the *Person* class; Yousef owns the apartment 11; Yousef was one of parties in the merging land operation ID of "MergingLandObjects20110225"; Ismail is the father of Yousef; Yousef is part of the land tenure dispute ID of "CaseIDP201501AhDa"; Yousef, Omar, Rasha, and Khalid are siblings; Yousef is the claimer of the "YousefClaimTr" claim ID; and Yousef has a claim on the land object ID of "IsmLandObj01". From the inferred information, stakeholders can gain a more comprehensive understanding of the dispute. For instance, it was revealed that Yousef had supported the amalgamation of Ismail's land object "IsmLandObj01", and Hami's land object, "HaniLandObj02." As a result, Yousef's role in extending the dispute from an internal to an external conflict is highlighted, and the reason for why the next-door neighbour claims the right to share Ismail's land is deduced. Stakeholders can also determine that Yousef completed this transaction under the enabling conditions of war. Moreover, inferred information can assist stakeholders in determining the relationships between individuals. In the dispute, Yousef, Omar, Rasha, and Khalid are all siblings, and therefore under Islamic law they are entitled to a part of the land. Finally, the inferred information illustrated that Yousef had a number of other claims. It was discovered that he owned another apartment and made claims for another transaction, "YousefClaimTr." With this information, further questions are elicited, such as: Why does he also own another apartment? How did he obtain it? Why does Yousef have a claim for another transaction? Such questions can further assist stakeholders in investigate this particular land tenure dispute.

Figure A.9 shows that the integrated techniques inferred the following: Hani is an individual of the *Tenant* class, including the *Person* class; Hani is the owner of the following apartment numbers: 45, 34, 23, and 12; Hani is one of the parties in the land operation ID of "MergingLandObjects20110225" where Yousef is part of this operation; Hani is part of the land dispute ID of "CaseIDP201501AhDa"; and Hani is the claimer of the "HaniIsmailFamilyClaimTe2015" claim. From the information inferred and illustrated in figure A.9, stakeholders can confirm that Hani is the next-door neighbour took part in the tenure transaction that amalgamated Hani's land object and Ismail's land object. Moreover, there is an additional dispute between Hani and Yousef, an open case dispute, "CaseIDP20150AhDa," that is revealed by the TTN database's integrated data mining and social networking tools.

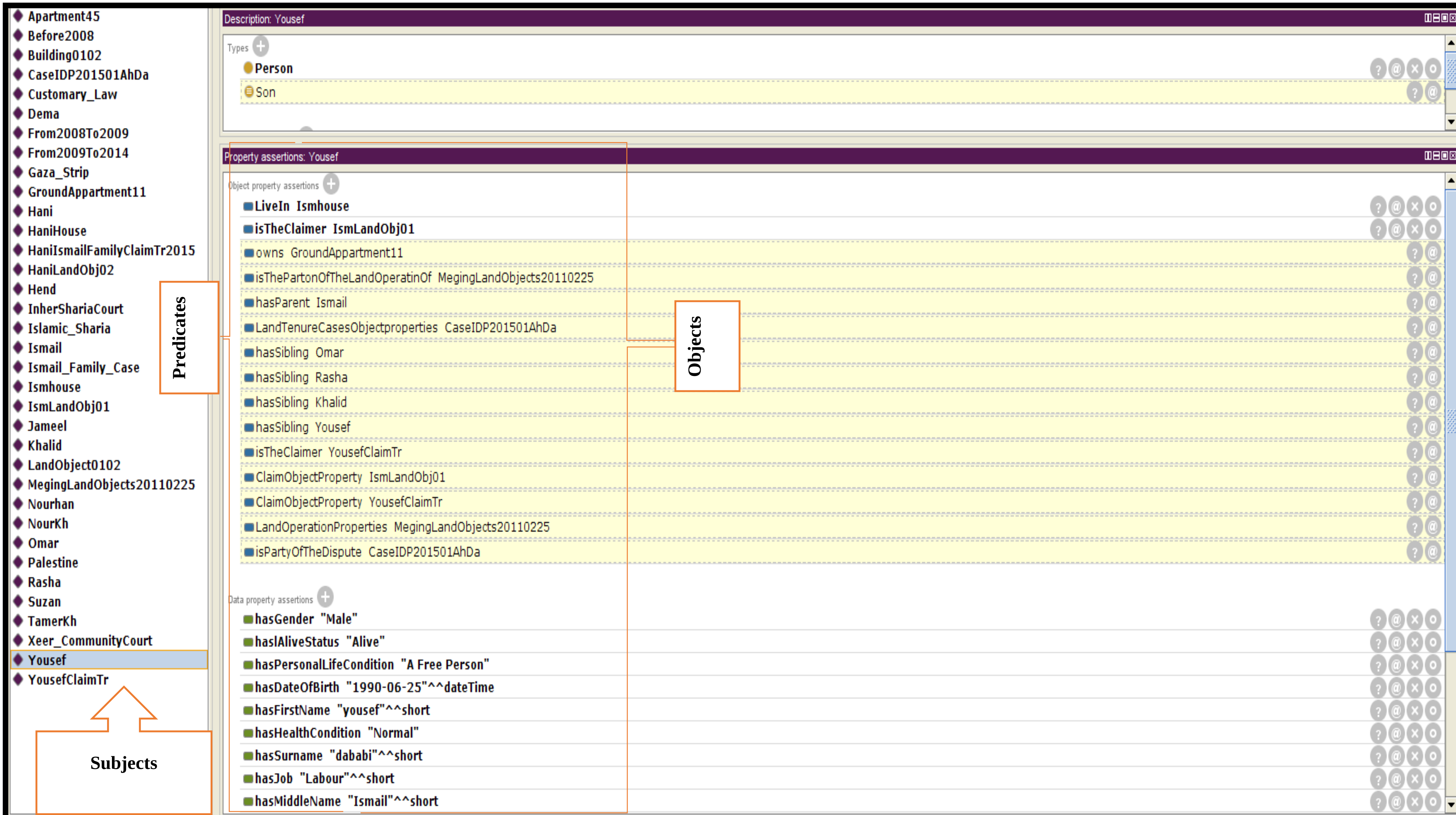

Figure A.8. Yousef’s hidden information – Palestinian Tenure Information

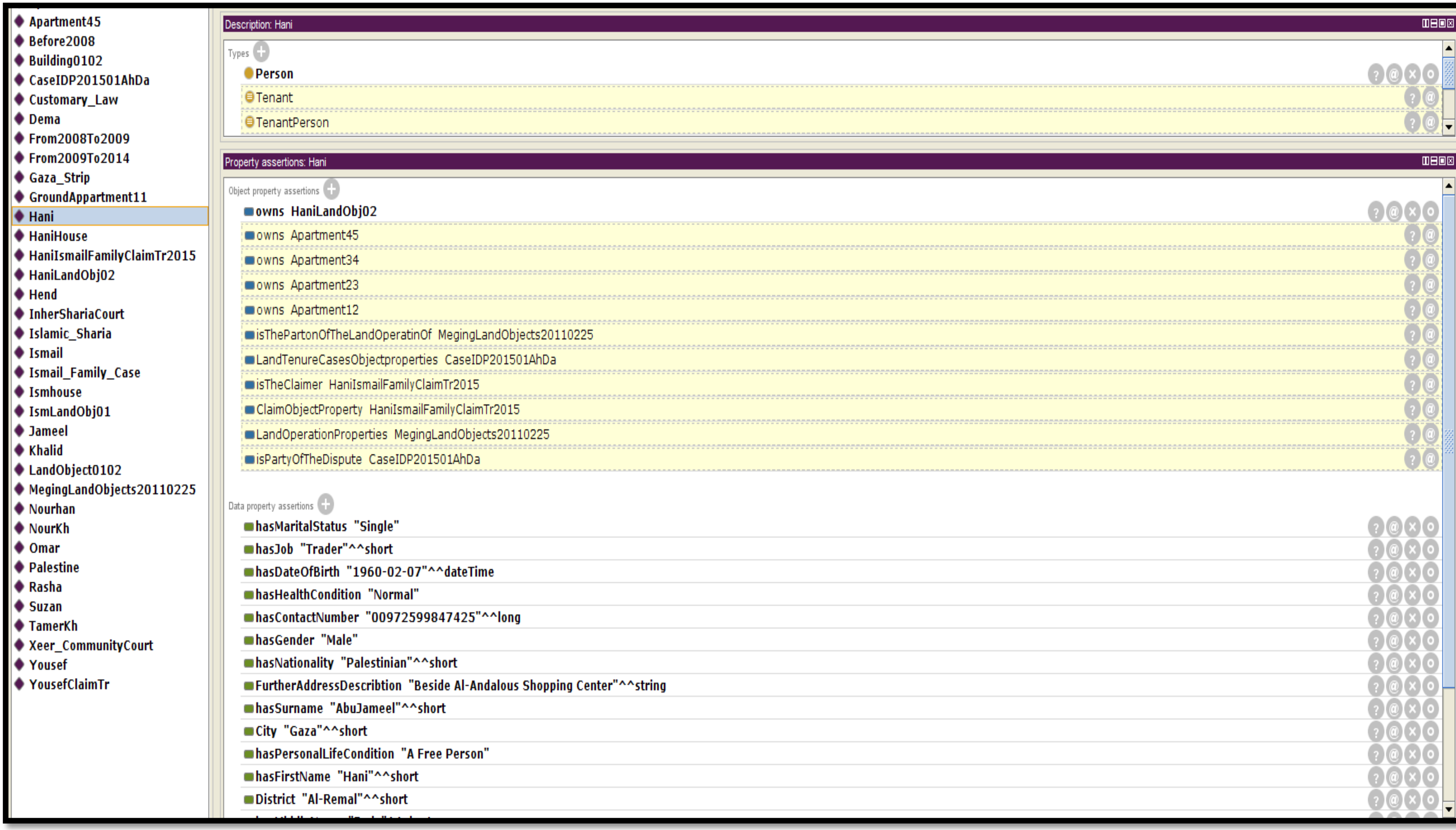

Figure A.9. Hani's hidden information – Palestinian Tenure Information

A.6 Relevance

This conflict is multifaceted and complex due to many interconnected relationships and different tenure details. It consists of two interrelated tenure disputes that cannot be separated easily. The internal dispute involves an inheritance dispute among family members over property. The external tenure dispute involves a dispute over the same property between the family members and their next-door neighbor. The TTN database can effectively capture tenure details of the internal and external tenure conflicts, and highlight the implicit relationships involved, which is important when analysing the scenario's complexity and fully understanding its aspects.

In addition, the integrated data mining technique of the TTN database enabled it to reveal hidden tenure relationships among and between persons, tenure operations, and tenure objects. For example, the TTN database was able to infer and describe the history of the amalgamation of Hani's and Ismail's land objects before the 2009 war. It shows that prior to the amalgamation of Hani's and Ismail's land objects, "LandObject0102" was two land objects: "IsmLandObj01" (Ismail's land before 2009) and "HaniLandObj02" (Hani's land before 2009). Also, it shows the history of "IsmLandObj01": how it was part of an inheritance tenure dispute; how it became a part of land object "LandObject0102"; and how it was converted into an apartment, "GroundApartment11", in building "Building0102". In addition, the TTN shows the point in which an internal conflict evolved from the inclusion of external factors.

For this scenario, stakeholders need to understand the relationship of the parties involved, the history of the property division, and the interrelatedness of internal and external factors, in order to discuss and resolve the inheritance problem with Yousef and his informal agreement with Hani. Stakeholders can send Yousef's family to *Sharia* court. After that, they can mediate the external conflict with Hani through social negotiation processes with the support of a *Makhateer* in the community. Misrepresenting these relationships could lead to more violence and further inflame the situation. Thus, the TTN database is designed to extract and visualise hidden relationships from the entered data to assist stakeholders in understanding and resolving multifaceted and complex tenure disputes.

Appendx B: Somaliland Case Study

B.1 Somaliland land tenure case study

Appendix B provides an overview of the simulated land tenure scenario for Somaliland, a post-conflict situation. The motivation for choosing this region is described in section 1.6. This appendix discusses the methodology used to simulate the Somaliland scenario which was used to test the TTN database prototype's functionalities for a post-conflict situation. The author simulated a land tenure scenario for Somaliland based on the literature review and data gathered by the author's supervisor (Barry 2006). Data used in the Somaliland scenario consists of secondary data.

Appendix B contains diagrams from the TTN database that illustrate the test results from the entered Somaliland land tenure data. People-people, people-land, clan-clan, clan-sub-clan, land-land, and people-media relationships, inheritance tenure transactions, and informal tenure transactions were entered and tested in the database. To capture this scenario, the following classes were used and tested: *CaseArea*, *CaseCountry*, *CaseID*, *CaseName*, *Claim*, *CourtName*, *Family*, *LandObject*, *InheritanceTransaction*, *TenureTransaction*, *Person*, *ShariaLaw*, *StagesNumberBasedYear*, *XeerLaw*, and *YearStamp*. The description for each class is shown in Appendix C.1.

The limitations of Somaliland scenario are that the scenario is not real, limited to the objective(s) that the data was collected for, and biased to the objectives of this research.

The following subsections describe the terminology and the simulated scenario of Somaliland. The author used pseudonyms in the simulated scenario.

B.2 Overview

This scenario provides tenure data to test the TTN database's functionalities for an ongoing conflict situation. The tenure data from the scenario provides an example of some of the multifaceted tenure relationships that may exist in ongoing conflict situations and serves as a sample tenure dispute that users of the TTN database may deal with. This illustrative case describes complex tenure relationships that are not easily identified and understood by stakeholders, as there are multiple interconnected networks and sub-networks of tenancy.

This section is organised as follows: (i) methodology for generalizing the Somaliland land tenure scenario; (ii) test results and analysis; and (iii) relevance.

B.3 Methodology for generating the Somaliland land tenure scenario

The scenario describes multifaceted land disputes among clans and sub-clans. The scenario was simulated using the same steps described for the Gaza strip scenario. The steps used to generate the Somaliland scenario are elaborated upon in further detail below:

1. Identifying the problem situation from the literature review:

This section describes the land tenure in Somaliland and the characteristics of tenure conflict situation in this region. In 1988, a civil war occurred in Somalia, and it continued for two years. About 500,000 people fled their homes, and 40,000 people were killed (Barry 2006). In 1991, the North West part of Somalia, the former British Protectorate of Somaliland, unilaterally declared independence (UDI) from Somalia and henceforth would be known as Somaliland. The international community did not recognize Somaliland's independence, even though the civil war forced many people from the capital city, Hargeisa, and other Somaliland areas to flee and claim refugee status in Europe, North America, and neighboring countries. When the war subsided in Hargeisa, the urbanization process began to take place. A substantial number of Somalians from the Somaliland area and Somalia moved to Hargeisa because they had relatives there and the economy was growing. As a result, informal settlements were built in urban zones to host the newcomers. This caused many land conflicts, which in turn led to an increase in homicide and violence-incidents rates (Barry 2006; Barry and Bruyas, 2007).

2. Determining the key elements of the problem situation from the literature review:

The key elements of the problem situation consists of institutions, clans, sub-clans, social rituals, tenure relationships, and inheritance disputes. These elements are what informed the TTN database classes (see figure C.1 in appendix C.1).

Social structure in Somaliland influences tenure relationships in the region. Somaliland is a semi-nomadic society, in which the concepts of clans, sub-clans, tribal elders, and lineage group predominate. Isaaq's clan is the largest clan in Somaliland, as it represents about 80% of Somaliland's population (Barry 2006). Other clans, such as Gaddaboursi, Dolbahante, and Warsangeli, are also large in size and have political influence in society.

Clans have their own customary land law, known as *Xeer,* which greatly influences Somaliland society. The *Xeer* customary law is founded on principles influenced by nomadic pastoral behavior. Other land laws that are found in Somaliland include both *Sharia* and secular laws. *Sharia* land law is formulated on the basis of the Islamic religion. Secular law is enacted and enforced by the municipality (PDRC 2003). Customary laws also play an influential role, in addition to *Sharia* and secular laws. Furthermore, most Somalians convey their tenure transactions using a private conveyance system. There is a governmental land registration office, but most people choose not to register. People may choose instead to privately register their land, by having a notary formulate a contract or deed. The signed deed, or contract is archived by the notary. When land conflicts arise, people prefer to go to the court or courts that are more likely to support their claims. Tenants may submit to *Sharia* courts, *Xeer* courts, and/or secular courts (Barry 2006).

3. Determining and understanding the interrelationships among the different elements of the problem situation:

This section describes different tenure relationships between and among people and tenure objects in Somaliland. These tenure relationships informed the relationships found in the TTN database (see tables C.1 and C.2). First of all, returning refugees are disputing land claims with current informal occupants. Moreover, tenants submit claims based on where they have the greatest support, with the possibility of a claim being submitted to different courts.

4. Describing the problem situation:

The scenario focuses on an inheritance problem among family members who have submitted their claims to two different authorities (*Sharia* court and customary law). The land was divided into two portions and one portion was inherited maternally. Then the civil war occurred and the inheritors fled the country. When they returned, they discovered that land was "illegally" occupied by maternal relatives.

5. Generating the simulated problem situation:

This section simulates a tenure dispute in Somaliland based on the above sections. The scenario took into consideration the complexities of a war which displaced claimants, the submission of claims to different authorities, and the significance of complex tenure relationships. The scenario is described below.

This scenario is about a conflict between two clans over land parcel "LandObjH0113" located in Hargeisa. The conflict dates back many years. The conflicting parties of the dispute are the Ghandy and Khaldoun clans. The following are the details of the conflict:

- Taher Ghandy was living in Hargeisa city. He got married to Dema, and they had two children: a son called Fady and a daughter called Hoda. Taher owned land object “LandObjTI01” in Hargeisa city.

In 1960, these events took place in Taher’s clan, respectively:

- Fady got married to Nourhan and had a son called Jameel Ghandy;
- Hoda got married to Mostafa Dareed and had a daughter called Ihsan Dareed; and
- Taher and Dema passed away.

In 1962, the Islamic court divided the land object and gave Fady two thirds of his father’s land object, while Hoda received one third, based on the inheritance law. Both of them received their respective deeds from the court, where Fady’s land object ID is “LandObjF0123” and Hoda’s land object ID is “LandObjH0113”.

In 1980, these events took place in Mostafa Dareed’s clan, respectively:

- Ihsan got married to Waleed Khaldoun, and they had a son, Marwan Khaldoun;
- Hoda and Mostafa passed away; and
- Ihsan Khaldoun submitted an ownership claim in *Sharia* court over the land object ID “LandObjH0113”. Based on the inheritance law, the court gave ownership rights over “LandObjH0113” to Ihsan Khaldoun.

Then in 1990, Ihsan and Waleed lost their lives due to the civil war in Somaliland. Marwan fled the war and immigrated to Europe. Courts and registration places were bombed and many civilian land documents were destroyed.

Figure B.1. Informal settlements in Hargeisa city (Barry 2006)

In 2015, Marwan returned to discover that Ghandy's clan occupied his land, and that Jameel Ghandi had developed the land. Marwan had lost his mother's ownership documents and was required to submit an ownership claim over land "LandObjH0113" in a *Sharia* court. Ghandy's clan, on the other hand, submitted an ownership claim over the same land object in a customary *Xeer* court. Both of the two clans, Ghandy and Khaldoun, are now in dispute over the land.

B.4 Test results and analysis

B.4.1. Capturing and describing tenure information

This tenure scenario is complex, as it consists of many interlocking relationships among clans, sub-clans, and land objects. These relationships describe inheritance issues over different land objects among individuals of different clans and sub-clans from four generations (see figure B.2). Inheritance in this case is problematic because it consists of hidden marital relationships, daughters inherited land and married into other clans and sub-clans. As seen in figure B.2, “LandObjT101” was divided into two properties and a part of the property “LandObjH0113” was inherited through different clans. These complications may challenge stakeholders in understanding an inheritance tenure dispute.

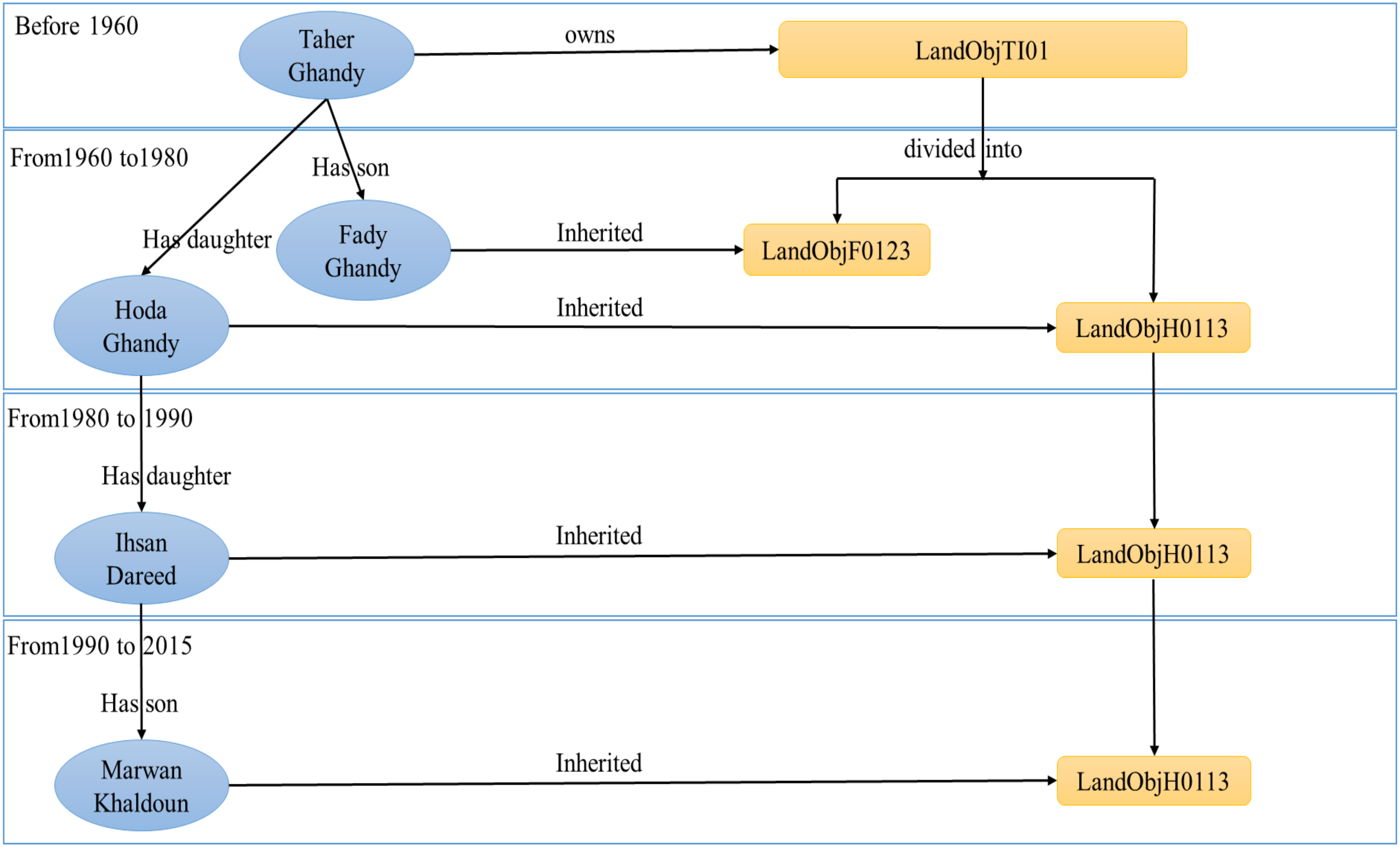

Figure B.2. Tenure relationships in the Somaliland scenario

After capturing the tenure data from the scenario, the TTN database classified the captured data according to the defined TTN relationships (see figure B.3). These classifications describe different attributes of the captured tenure data in the TTN database, such as case areas, number of claims, types of claims, and clans involved. These descriptions may help stakeholders distinguish different tenure elements to extract patterns that may help them understand the structure of the society.

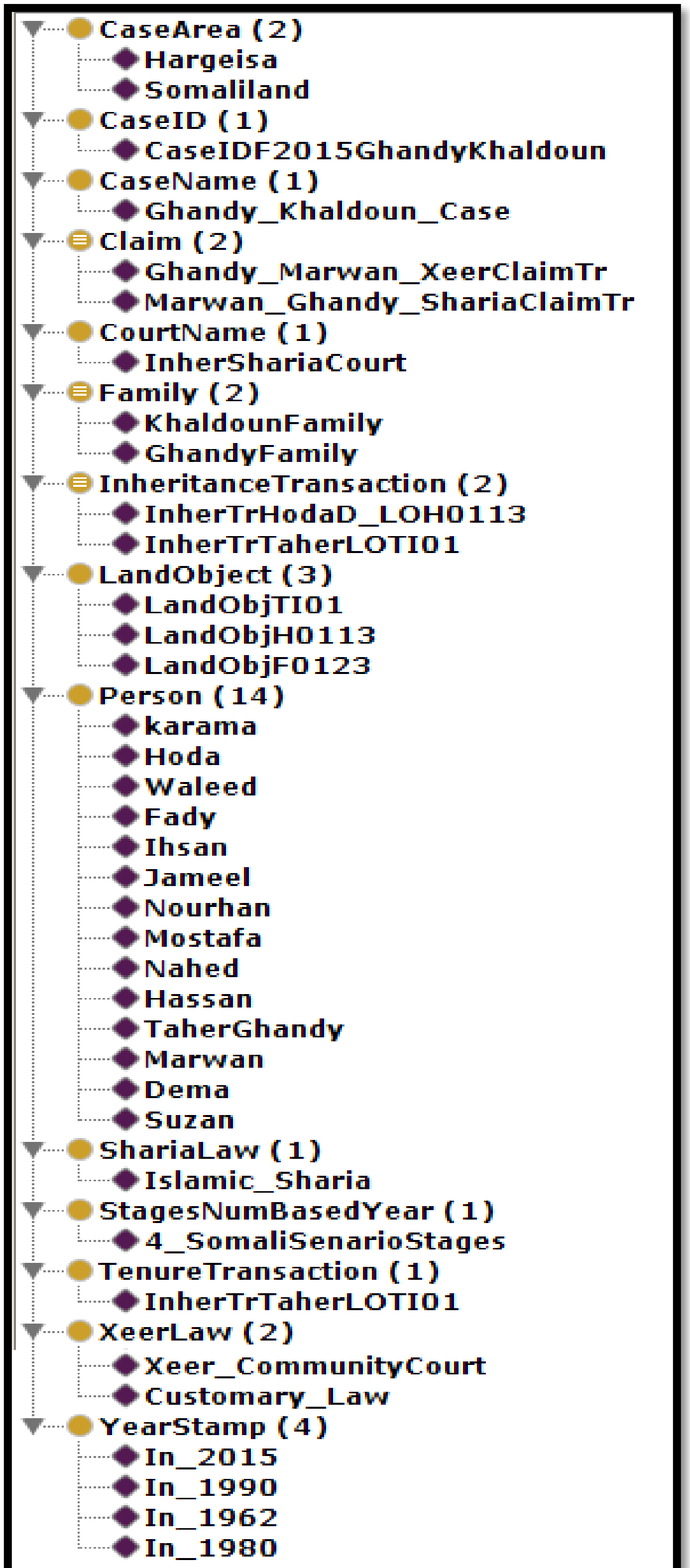

Figure B.3. Classifying Tenure Information - Somaliland Case

The database illustrated the linkages between members of the clan and the property under dispute. As shown in figure B.4, the graph network can visualize the Somaliland case in the Star (Radial) mode. Through this mode, the complexity of the dispute can be simplified as the key tenure elements and relationships can be highlighted for further investigation. In figure B.4, interrelated the key tenure elements and relationships intersect to form a triangle. The nodes of the triangle are “InherTrTaherLOTl01”, “LandObjH0113”, and “Hoda.” As shown in figure B.3, these nodes are tenure transaction, land object, and person, respectively. These three nodes are the key elements of this inheritance tenure dispute and can be further examined.

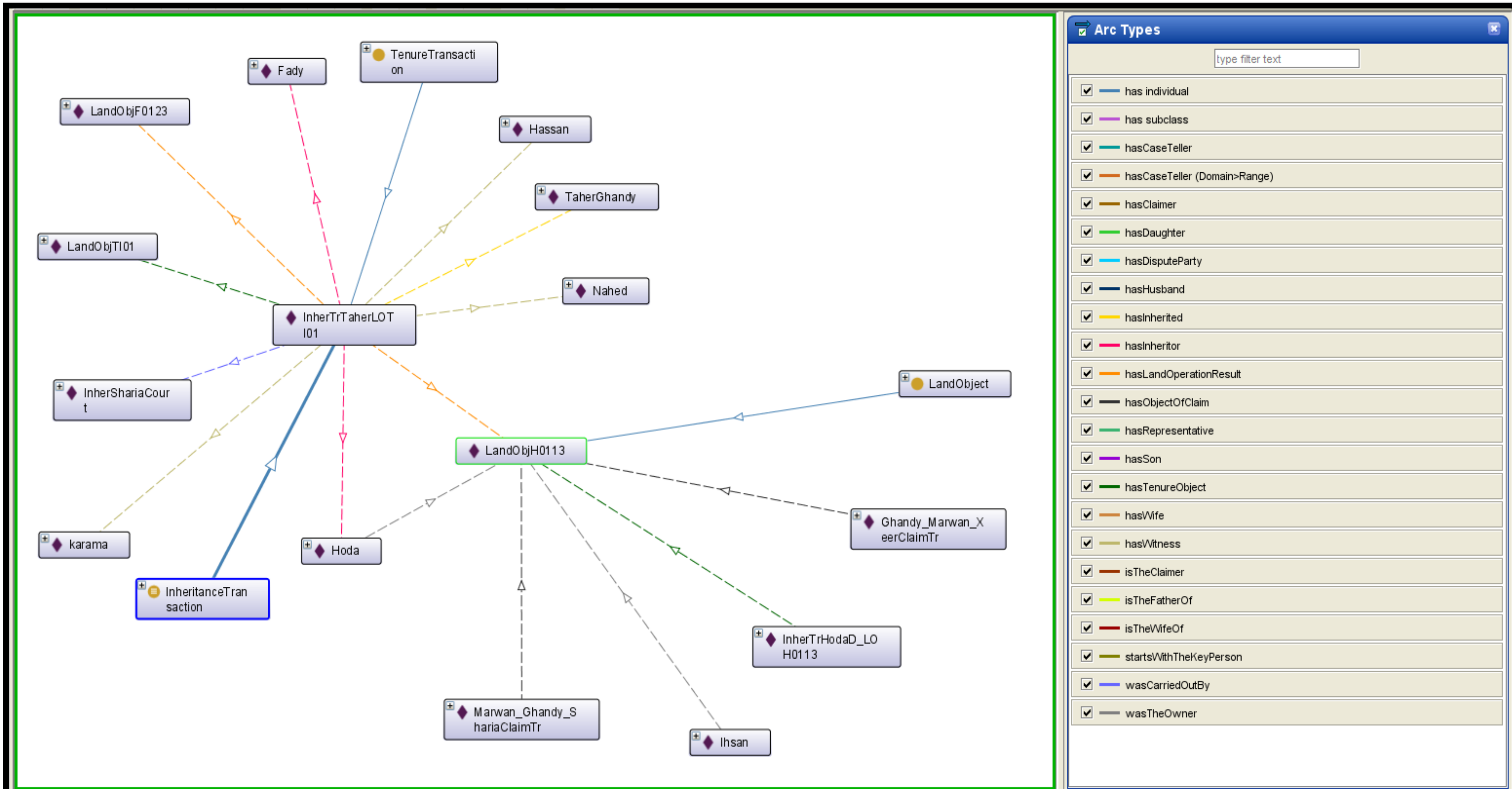

Figure B.4. Star TTN Network Mode - Somaliland Case

After further examining Hoda (see figure B.5), the TTN database was able to describe and visualize tenure relationships to show that land object “LandObjH0113” was inherited by Hoda through her father who belonged to Ghandy’s clan and was transferred to Marwan who belongs to Khaldoun’s clan. By extending Ihsan’s sub-star network, it can be determined that Ihsan is the key person who links Ghandy’s clan with Khaldoun’s clan. Ihsan married into Khaldoun’s clan and passed “LandObjH0113” to her son, Marwan. Ihsan’s sub-star network shows that Ihsan is the daughter of Hoda who first inherited the land of dispute. Also, it shows that Hoda and Ihsan were the owners of “LandObjH0113.” Also, it shows that Ihsan inherited the land from Hoda through the inheritance transaction “InherTrHodaD_LOH0113,” and Hoda inherited the land from her father, Taher Ghandy, through the inheritance transaction “InherTrTaherLOTl01.” The visualized network in the figure B.5 may assist in determining the key persons that have and had tenure relationships with the land in dispute and understand how the land was transferred to Marwan. The thick dash-lines illustrate Ihsan’s connections to the Ghandy’s clan through Hoda and Marwan’s clan. This visualization mode may assist stakeholders in understanding the maternal relationships between Marwan and Ghandy’s clan; “LandObjH0113” (the land in dispute) and Marwan; and “LandObjH0113” and Ghandy’s clan.

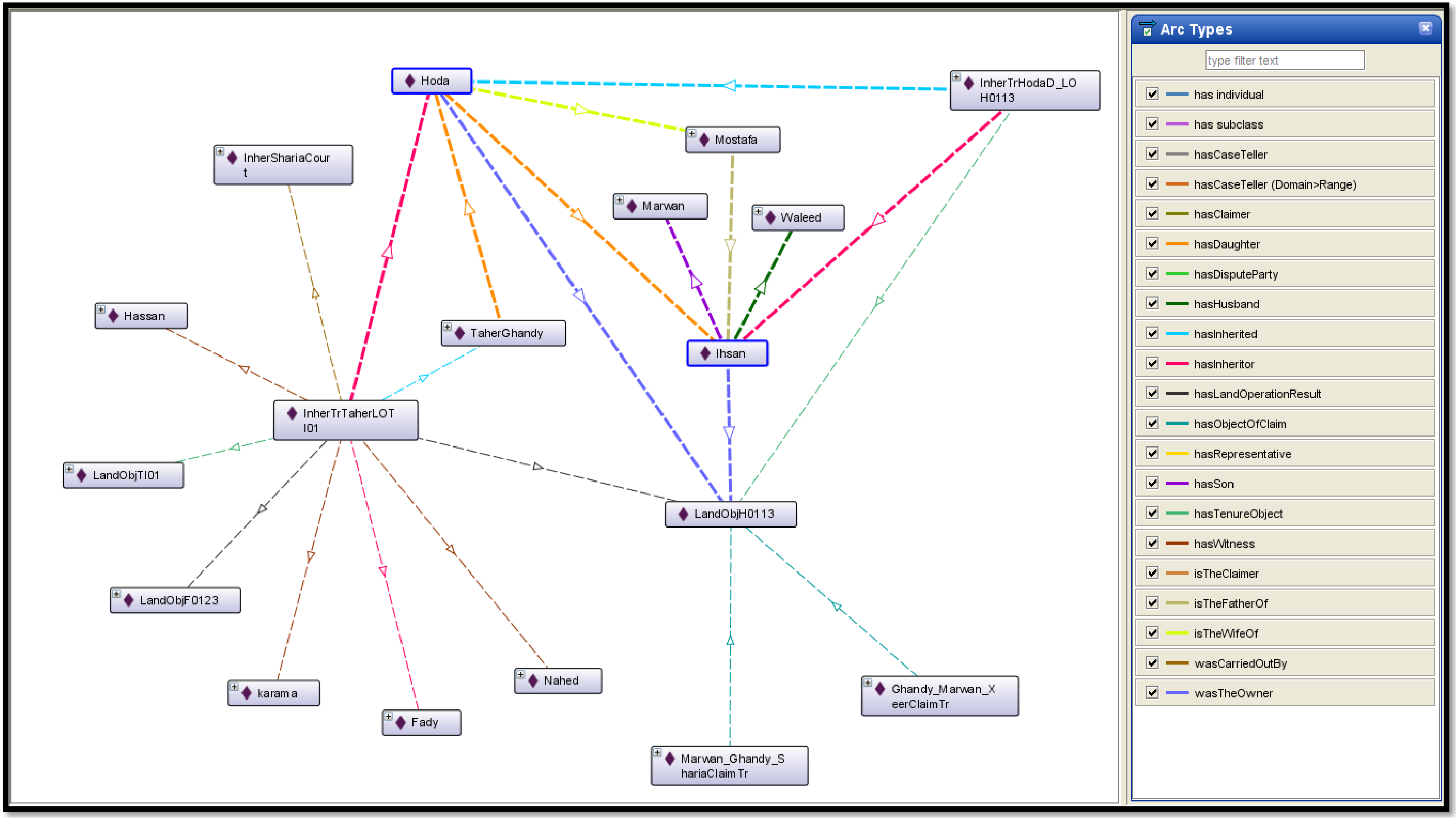

Figure B.5. Expanded Star TTN Network Mode - Somaliland Case

B.4.2. Supporting data mining and social network analysis techniques

The TTN database was able provide rich descriptions about the tenure dispute by inferring hidden tenure relationships specific to matrimonial property that were not entered in the database. These relationships may be significant for stakeholders to consider when resolving a conflict. They may help stakeholders trace different tenure relationships to understand the dispute. For example, figures B.6 and B.7 illustrate hidden tenure information extracted by the TTN database about Marwan and Ihsan, respectively. As shown in figure B.6, the integrated data mining and social network analysis inferred the following: Marwan is an individual of the *Son* class, including the *Person* class; Marwan is the son of Ihsan; Marwan is part of the land dispute ID of "CaseIDF2015GhandyKhaldoun"; Marwan is the grandson of Mostafe and Hoda; Marwan is the claimer of the "Marwan_Ghandy_ShariaClaimTr" claim; and Marwan is the representative of Khaldoun's family. Figure B.7 shows the inferred information and relationships about Ihsan. The integrated data mining and social network analysis techniques in the TTN database extracted the following: Mostafa is Ihsan's father; Waleed is Ihasn's husband; Hoda is Ihsan's Mother; the grandparent of Ihsan is Taher Ghandy; and Ihsan is the mother of Marwan; Ihsan an inheritor of the inheritance transaction "InherTrHodaD_LOH0113."

This extracted information can be crucial for stakeholders to consider in order to support the social negotiation process. The database provides an opportunity to trace property transactions between clans over different generations and to illustrate the origin of these transactions. From the extracted relationships, stakeholders may find key elements. For example, it could be beneficial for stakeholders to understand that there are maternal relationships among

Marwan’s, Khaldoun’s, and Ghandy’s clans; and to note that land object “LandObjH0113” was owned by Ghandy’s clan before being inherited to Marwan Khaldoun from his mother, Ihsan.

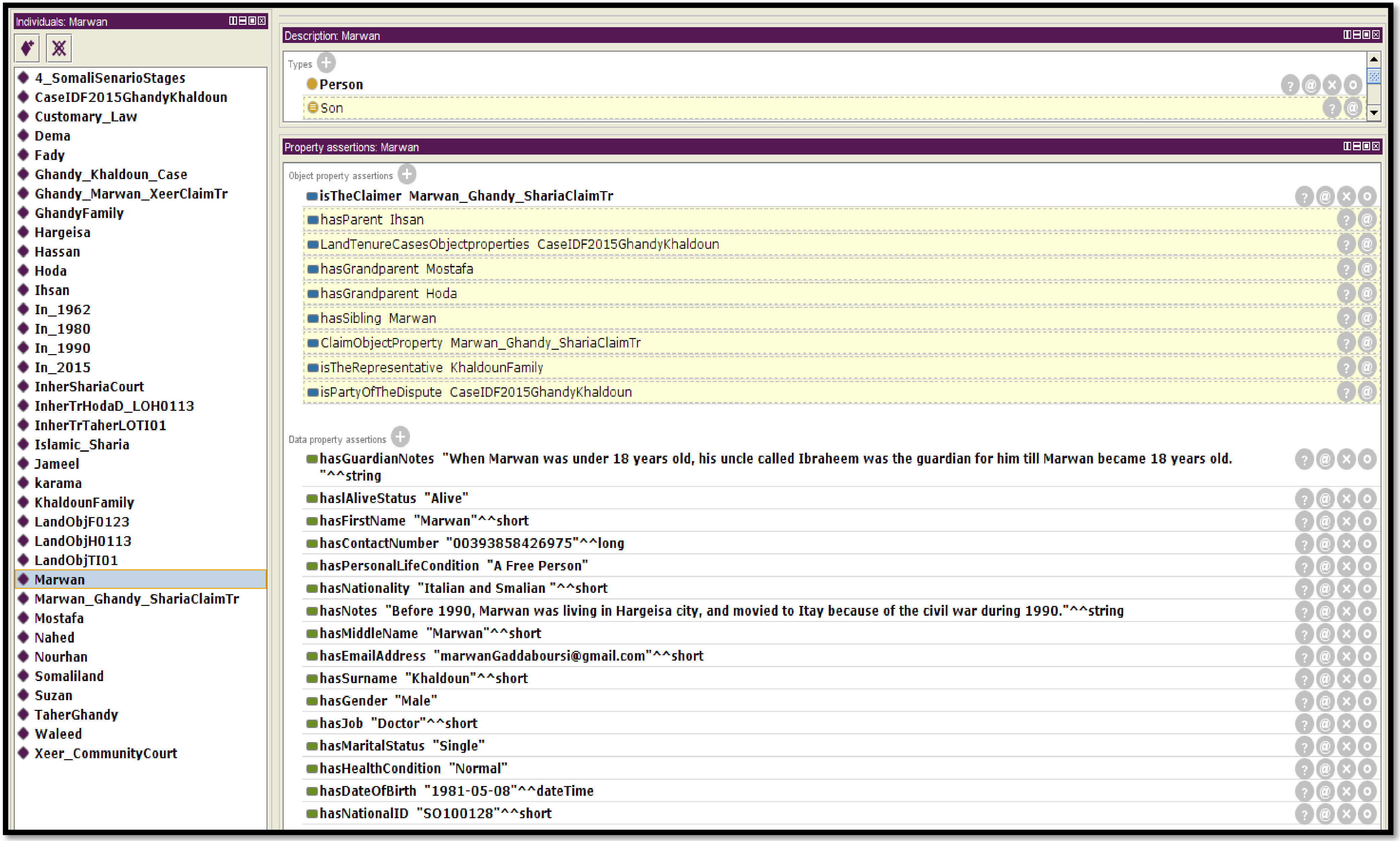

Figure B.6. Marwan's hidden information - Somaliland Tenure Information

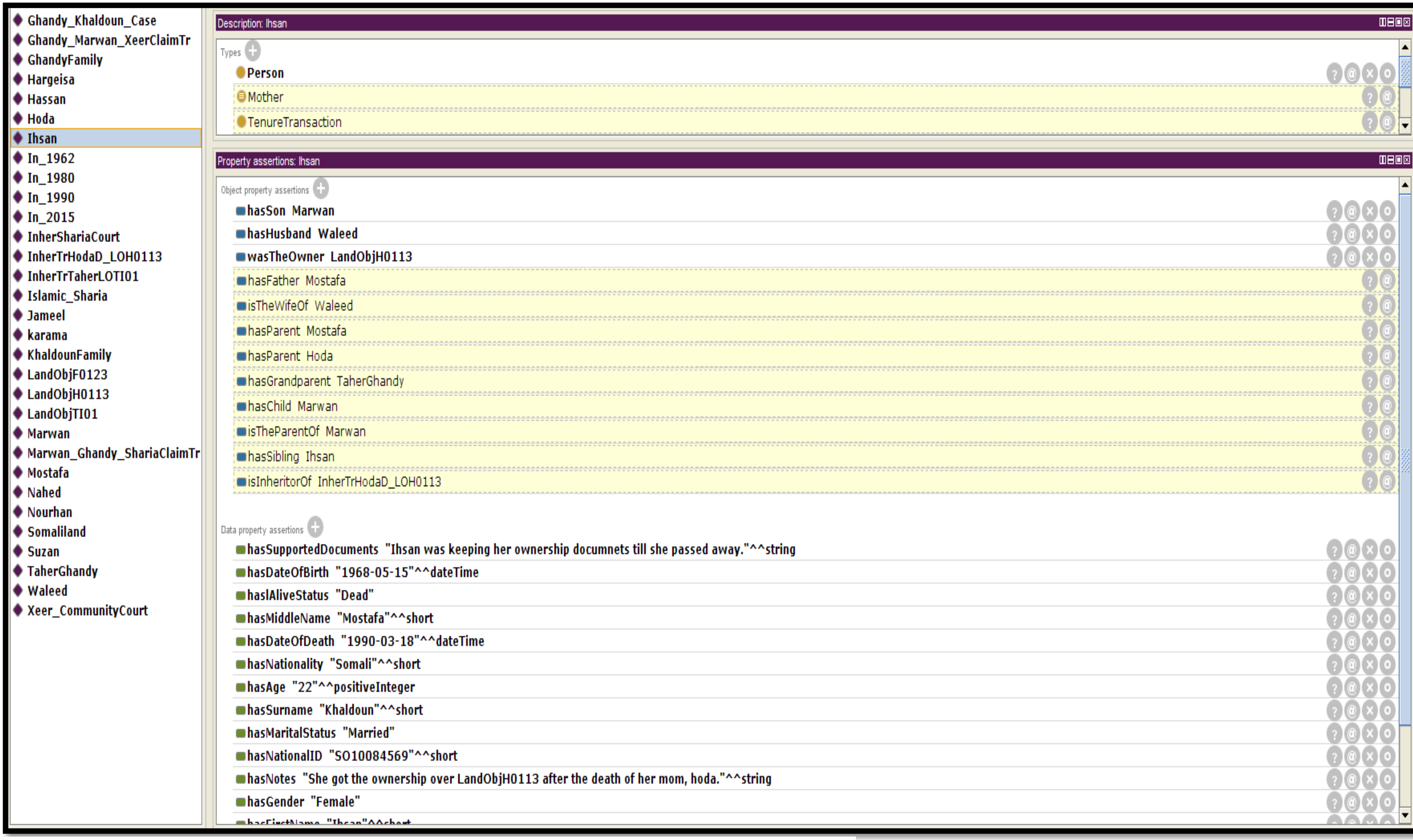

Figure B.7. Ihsan's hidden information - Somaliland Tenure Information

B.5 Relevance

This conflict is complex due to many interconnected relationships and different tenure details. A LTIS database that can effectively capture tenure details and highlight the implicit relationships involved is important to analyse the scenario's complexity and fully understand its different aspects. For instance, the land lot "LandObjH0113" was part of the land lot "LandObjTI01" before the death of Taher Ghandy. Also, it is important to note implicit relationships among persons, especially the maternal relationships. Maternal relationships are often hidden and ambiguous. For example, Marwan Khaldoun, Ihsan Dareed, Hoda Ghandy, and Taher Ghandy are all relatives from their mother's side, but have different clan names because they took on their husbands' clan names when they were married. For this scenario, the ownership rights over "LandObjH0113" were dictated in accordance with *Sharia* inheritance laws, in which one's position within the family is of great importance. Misrepresenting these relationships could lead to more violence and further intensify the situation. Thus, the TTN database is designed in a way that extracts hidden relationships among different items of information. Selecting different tenure elements (see Appendix C) will help the user investigate different parts of the issue. By selecting individuals in the Property Assertions box in the Protégé software, stakeholders can see matrilineages more clearly; by selecting specific claims in the Property Assertions box, stakeholders can see the individuals associated with a given claim. By using the TTN database, stakeholders may gain a better understanding of a land case

Appendx C: Technical components of the TTN database design

This appendix illustrates the classes and the relationships that were programmed by the author to develop the TTN database design. Other classes and relationships that were not used to capture and describe the Palestinian and Somaliland scenarios are incorporated in the TTN database design. The author was not able to test all of these classes and relationships because they were not part of the Palestinian and Somaliland scenarios. Therefore, it is highly recommended to test the TTN database using different tenure scenarios in order to examine classes that were not used in the experimental tests.

C.1 TTN Classes

Triple Store database has a default root class called *Thing*. Thus, TTN classes are subclasses of the *Thing* class. The defined TTN classes are shown in figure C.1.

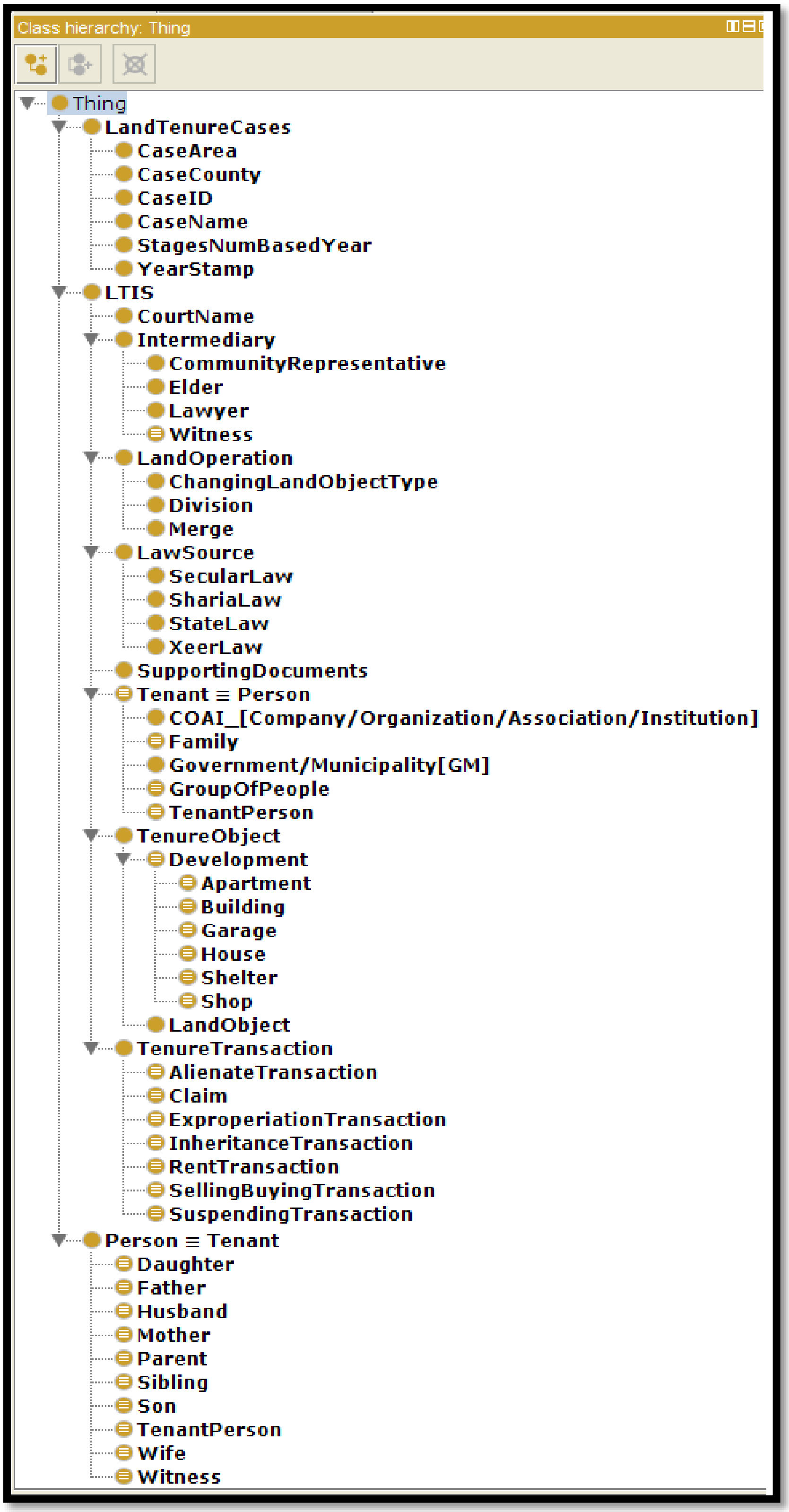

Figure C.1. TTN Database Classes

As shown in figure C.1, TTN database consists of three main classes: *LandTenureCases*, *LTIS*, and *Person*. The *LandTenureCases* class consists of different sub-classes which capture previous land tenure dispute stories. The *LTIS* class consists of different sub-classes that capture land tenure information and different tenure transactions. The *Person* class consists of different sub-classes which capture detail about persons (*e.g.* tenant, lawyer, and witness). These classes/sub-classes are all connected through different tenure relationships to describe different components within a land scenario (*e.g.* land object, tenant, transaction(s), and social relationships). The following is the description of each class:

1. *LandTenureCases* captures and provides a brief description about a land tenure dispute claim. Specifically, it describes a land conflict scenario in different periods of time, and it describes the area of the conflict. This class consists of the following subclasses: *CaseArea*, *CaseCountry*, *CaseID*, *CaseName*, *StagesNumBasedYear*, and *YearStamp*. The following describes each sub-class:

1.1. *CaseArea* captures and describes the area of a conflict which could be a district, a community, a small area, or a neighborhood. Describing the area of a land conflict is important in order to draw upon the inhabitants' culture. People's culture may differ in different communities or regions. For example, the culture and rituals of people who are living in rural areas may differ than those of people who are living in the capital city.

1.2. *CaseCountry* captures and describes the county of the conflict area.

1.3. *CaseID* captures and provides a unique land tenure case Identification (ID) for each case.

1.4. *CaseName* captures and describes the alias name of a land tenure scenario.

1.5. *StagesNumBasedYear* contains the number of stages or time stamps of a land dispute scenario. During the age of a land dispute, significant events (*e.g.* occurrence of war, death of a tenant, changing land type, etc.) may affect the conflict noticeably. These events may change the nature of the dispute, and different generations witness these changes. Therefore, the *StagesNumBasedYear* class describes the number of time stamps (stages) for a conflict. Each stage describes a land dispute within a specific period of time.

1.6. *YearStamp* captures and describes part of a land tenure dispute within a specific interval of time. An interval of time could be defined as a stage within this context. Each stage has a beginning year and an ending year. The *YearStamp* class briefly describes a land conflict within a specific stage.

The purpose of the *StagesNumBasedYear* and the *YearStamp* classes is to provide a strong brief description of such a land conflict to stakeholders. The brief description helps stakeholders to follow and understand the conflict scenario when they get further involved within the conflict detail and its numerous social-tenure relationships.

2. *LTIS* captures and describes tenure transactions and the associated social and tenure relationships with each transaction. The *LTIS* class consists of different classes and sub-classes. These classes/subclasses are necessary to describe different types of tenure transactions. These sub-classes are described as follows:

2.1. *CourtName* captures and describes the names of different courts.

2.2. *Intermediary* captures and describes the different social roles of a person within a land tenure scenario, such as a community representative, an elder, a lawyer, and/or a witness. The *Intermediary* class consists of the following four sub-classes:

2.2.1. *CommunityRepresentative* captures and describes persons who are community representatives.

2.2.2. *Elder* captures and describes persons who are clans' elders.

2.2.3. *Lawyer* captures and describes lawyers involved within a tenure transaction.

2.2.4. *Witness* captures and describes witnesses who witnessed a tenure transaction.

2.3. *LandOperation* captures and describes the possible tenure operations that can be performed on a land object, such as changing land type (*e.g.* public land to private land), dividing a land lot into sub-lots, and merging two parcels of land to become one land object. The *LandOperation* class consists of the following three sub-classes:

2.3.1. *ChangingLandObjectType* captures and describes the change of a land type (*e.g.* public land, private land, forest land, etc.)

2.3.2. *Division* captures and describes the division operation of a land object.

2.3.3. *Merge* captures and describes any merging operation of different land objects.

2.4. *LawSource* captures and describes the law source of a court, such as secular law, *Sharia* law, Statute law, and *Xeer* law. For example, Islamic courts apply *Sharia* law for judging people's claims, whereas the *Xeer* applies customary law.

2.5. *Tenant* captures and describes different types of tenants, such as company, organization, association, institution, family, government, municipality, group of people, and person. This class is equivalent to the *Person* class because all the different types of tenant are represented by a person. Based on the person relationships, the person is classified as an individual of one or more of the following sub-classes:

2.5.1. *COAI [Company/ Organization/ Association/ Institution]*.

2.5.2. *Family*.

2.5.3. *Government/Municipality[GM]*.

2.5.4. *GroupOfPeople.*

2.5.5. *TenantPerson.*

2.6. *TenureObject* captures and describes different types of tenure objects. A tenure object can be one of the following types: a land object, or a development. The development type consists of the following sub-types: building, shelter, shop, house, apartment, and garage. Tenure objects are distributed among these classes based on their established relationships. The *Development* class is only for describing constructed objects on a land object. Therefore, the *Development* class consists of a list of sub-classes to describe the different types of constructions. The following are the sub-classes of the *Development* class:

2.6.1. *Apartment.*

2.6.2. *Building.*

2.6.3. *Garage.*

2.6.4. *House.*

2.6.5. *Shelter*.

2.6.6. *Shop.*

Each sub-class of the *Development* class describes the characteristics that are associated with a specific type of construction through a bundle of established relationships. For example, the characteristics of an apartment are different than those of a garage. A garage is only developed on the ground floor of a building, while an apartment can be developed on any floor of a building. Therefore, the floor number can be used to describe one of the apartment features. It could not be used as a garage feature. Regarding the *TenureObject* class, it captures and describes information related to a land object.

2.7. *SupportingDocuments* captures and describes tenure documents such as picture(s), scanned document(s), recorded video(s), and recorded audio. This class captures these supporting documents as hyperlinks.

2.8. *TenureTransaction* captures and describes the possible tenure transactions. It consists of the following sub-classes in order to describe different types of tenure transactions:

2.8.1. *AlienateTransaction* captures and describes the alienate type of transaction.

2.8.2. *Claim captures* and describes different types of claims including ownership, inheritance, and rent among individuals on a tenure object.

2.8.3. *ExportationTransaction* captures and describes expropriation transactions performed by a governmental organization on a parcel of land.

2.8.4. *InheritanceTransaction* captures and describes inheritance transactions among family members on land objects, and/or developments.

2.8.5. *RentTransaction* captures and describes different rent agreements between parties on tenure objects.

2.8.6. *SellingBuyingTransaction* captures and describes purchase and selling transactions of tenure objects between parties.

2.8.7. *SuspendingTransaction* captures and describes suspending cases that could be applied by a governmental organization on a tenure object.

3. *Person* captures and describes social information (personal details and relationships) including different social roles, such as parent, mother, father, wife, husband, uncle, daughter, son, and sibling. Also, it describes other social roles that a person may have in a land tenure transaction such as witness, tenant, lawyer, representative, and elder. Therefore, the *Person* class consists of sub-classes to describe different social roles. Each subclass was defined by OWL and RDFS ontologies. The following are the descriptions of the subclasses:

3.1. *Daughter* captures and describes a person who is satisfying the following conditions: defined as an individual of the *Person* class, has parents, and has the "female" gender type.

3.2. *Father* captures and describes a person who is satisfying the following characteristics: defined as an individual of the *Person* class, married or divorced, has at least one child, and has the "male" gender type.

3.3. *Husband* captures and describes a person who is satisfying the following characteristics: defined as an individual of the *Person* class, has a wife, and has the "male" gender type.

3.4. *Mother* captures and describes a person who is satisfying the following characteristics: defined as an individual of the *Person* class, married or divorced, has at least one child, and has the "female" gender type.

3.5. *Parent* captures and describes a person who is satisfying the following characteristics: defined as an individual of the *Person* class, and has at least one child.

3.6. *Sibling* captures and describes a singular person who is an individual of the *Person* class and has a brother or sister.

3.7. *Son* captures and describes a person who is satisfying the following characteristics: defined as an individual of the *Person* class, has parents, and the "male" gender type.

3.8. *TenantPerson* captures and describes a person who is an individual of the *Person* class and owns or rents a tenure object.

3.9. *Wife* captures and describes a person who is satisfying the following characteristics: defined as an individual of the *Person* class, has exactly one husband, and has the "female" gender type.

3.10. *Witness* describes a person who is defined as a member of the *Person* class and has witnessed a tenure transaction.

Individuals are classified among the classes of the TTN database based on the relationships that are established between other individuals. These relationships are described in detail in section C.2.

The Triple Store database can define constraints on classes. In the TTN database design, some individuals are allowed to share classes, while other individuals are not allowed. For example, a person from the *Person* class cannot be a member of the *LandObject* class, but they can be a member of the *Wife* class. To prohibit the sharing of classes between individuals, these classes are defined as disjoint classes. The default of Triple Store database defines classes as joint classes. Figure C.2 illustrates some of the joint and disjoint classes in the TTN database.

As shown in figure C.2, the *LandTenureCases* class is disjoint with the *Person* and the *LTIS* classes. This means a *LandTenureCases* individual cannot be defined as an individual in the *Person* or the *LTIS* class. On the other side, the *LTIS* and the *Person* classes are not disjoint. Thus, they can share individuals. For example, in figure C.2, "X" is an individual of the *Wife* class which is a sub-class of the *Person* class. The *Tenant* class is a sub-class of the *LTIS* class. Since the *Tenant* class is not disjoint with the *Wife* class, the individual "X" can be defined in the two classes. The wife "X" can be a tenant if she owns or rents a tenure object. For the disjoint classes, the *CaseCountry* class is a sub-class of the *LandTenureCases* class, and the *LawSource* class is a sub-class of the *LTIS* class. The *LandTenureCases* class is disjointed with the *LTIS* class. Consequently, the *LawSource* class is disjoint with the *CaseCountry* class. Thus, the individual "P" of the *CaseCountry* class cannot be defined as an individual in the *LawSource* class. Joint and disjoint are inheritance features, which means if two classes are disjointed, then the sub-classes of the two classes are disjointed too.

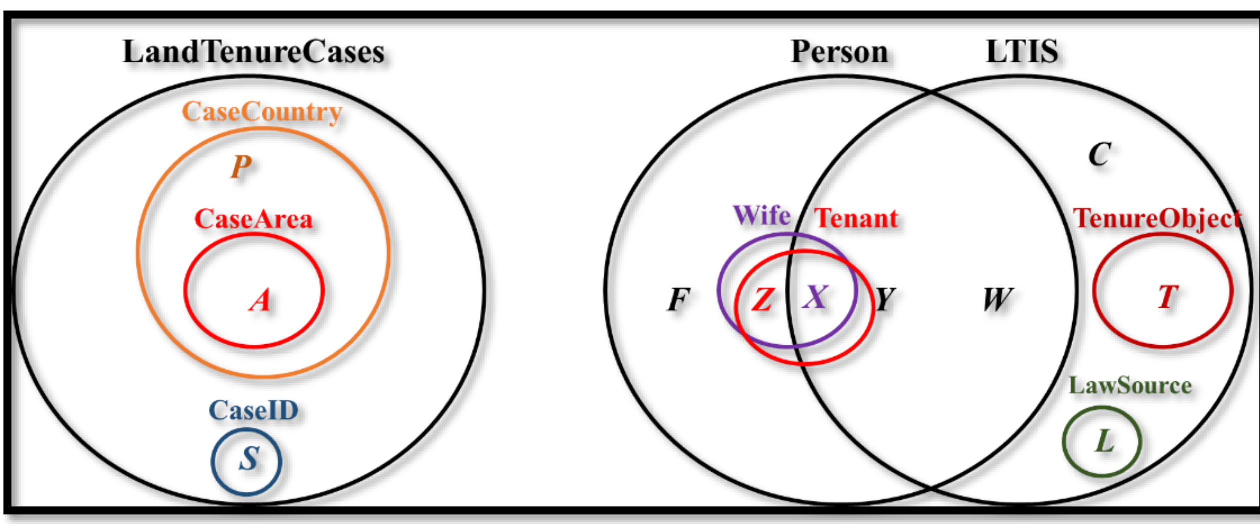

Figure C2. Disjoint and joint classes and subclasses

The following describes the disjoint classes of the TTN database:

- The *LandTenureCases* class is disjointed with the *LTIS* and the *Person* classes. As a consequence, the *LandTenureCases* class and its subclasses are disjointed with the sub-classes of the *Person* and the *LTIS* classes.
- The *CaseArea* class is disjointed with the following classes: *StagesNumbasedYear*, *CaseID*, *CaseName*, and *YearStamp*.
- The *CaseCountry* class is disjointed with the following classes: *StagesNumBasedYear*, *CaseName*, *CaseID*, and *YearStamp*. The *CaseArea* and the *CaseCountry* classes are not disjointed because an area is part of a country.
- The *CaseID* class is disjointed with the following classes: *CaseArea*, *YearStamp*, and *CaseCounrty*.
- The *CaseName* class is disjointed with the following classes: *CaseArea*, *CaseCountry*, and *StagesNumBasedYear*.
- The *StagesNumBasedYear* class is disjointed with the following classes: *CaseCountry*, *CaseArea*, and *CaseName*.
- The *YearStamp* class is disjointed with the following classes: *CaseArea*, *CaseID*, and *CaseCountry*.
- The *LTIS* class is disjointed with the *LandTenureCases* class.
- The *CourtName* class is disjointed with the following classes: *Tenant*, *LawSource*, and *LandOperation*.
- The *LandOperation* class is disjointed with the following classes: *CourtName*, *Tenant*, and *LawSource*.

- The *ChangingLandObjectType* class is disjointed with the *Division* and the *Merge* classes.
- The *Division* class is disjointed with the *ChangingLandObjectType* and the *Merge* classes.
- The *Merge* class is disjointed with the *ChangingLandObjectType* and the *Division* classes.
- The *LawSource* class is disjointed with the following classes: *CourtName*, *Tenant*, and *LandOperation*.
- The *SecularLaw* class is disjointed with the following classes: *ShariaLaw*, *StateLaw*, and *XeerLaw*.
- The *ShariaLaw* class is disjointed with the following classes: *SecularLaw*, *StateLaw*, and *XeerLaw*.
- The *StateLaw* class is disjointed with the following classes: *SecularLaw, ShariaLaw*, and *XeerLaw*.
- The *XeerLaw* class is disjointed with the following classes: *SecularLaw*, *ShariaLaw*, and *StateLaw*.
- The *Tenant* class is disjointed with the following classes: *TenureObject*, *CourtName,* *LawSource*, and *LandOperation*.
- The *Family* class is disjointed with the *TenureObject* class.
- The *GroupOfPeople* class is disjointed with the *TenureObject* class.
- The *TenureObject* class is disjointed with the following classes: *Family*, *Tenant*, *GroupOfPeople*, and *Person*.
- The *Development* class is disjointed with the *LandObject* class.

- The *LandObject* class is disjointed with the *Development* class.
- The *AlienateTransaction* class is disjoint with the following classes: *Claim*, *ExpropriationTransaction*, *InheritanceTransaction*, *RentTransaction*, *SellingBuyingTransaction*, and *SuspendingTransaction*.
- The *Claim* class is disjointed with the following classes: *AlienateTransaction*, *ExpropriationTransaction*, *InheritanceTransaction*, *RentTransaction*, *SellingBuyingTransaction*, and *SuspendingTransaction*.
- The *ExpropriationTransaction* class is disjointed with the following classes: *AlienateTransaction*, *Claim*, *InheritanceTransaction*, *RentTransaction*, *SellingBuyingTransaction*, and *SuspendingTransaction*.
- The *InheritanceTransaction* class is disjointed with the following classes: *AlienateTransaction*, *Claim*, *ExpropriationTransaction*, *RentTransaction*, *SellingBuyingTransaction*, and *SuspendingTransaction*.
- The *RentTransaction* class is disjointeded with the following classes: *AlienateTransaction*, *Claim*, *ExpropriationTransaction*, *InheritanceTransaction*, *SellingBuyingTransaction*, and *SuspendingTransaction*.
- The *SellingBuyingTransaction* class is disjointed with the following classes: *AlienateTransaction*, *Claim*, *ExpropriationTransaction*, *InheritanceTransaction*, *RentTransaction*, and *SuspendingTransaction*.
- The *SuspendingTransaction* class is disjointed with the following classes: *AlienateTransaction*, *Claim*, *ExpropriationTransaction*, *InheritanceTransaction*, *RentTransaction*, and *SellingBuyingTransaction*.
- The *Person* class is disjointed with the *LandTenureCases* and the *TenureObject* classes.

- The *Daughter* class is disjointed with the *Son* and the *Husband* classes.
- The *Father* class is disjointed with the *Wife* and the *Mother* classes.
- The *Husband* class is disjointed with the following classes: *Wife*, *Mother*, and *Daughter*.
- The *Mother* class is disjointed with the *Father* and the *Husband* classes.
- The *Son* class is disjointed with the *Daughter* and the *Wife* classes.
- The *Wife* class is disjointed with the following classes: *Father*, *Husband*, and *Son*.

Since classes' individuals are classified among the defined classes based on their relationships, the next section describes the defined TTN relationships.

C.2 TTN relationships

This section describes two types of TTN database relationships: object property and data property relationships. These relationships describe different relationships among individuals of classes and classifies them. The TTN relationships are hierarchically structured and listed in the form of properties and sub-properties. The defined TTN object and data property relationships are shown in figures C.3 and C.4, respectively.

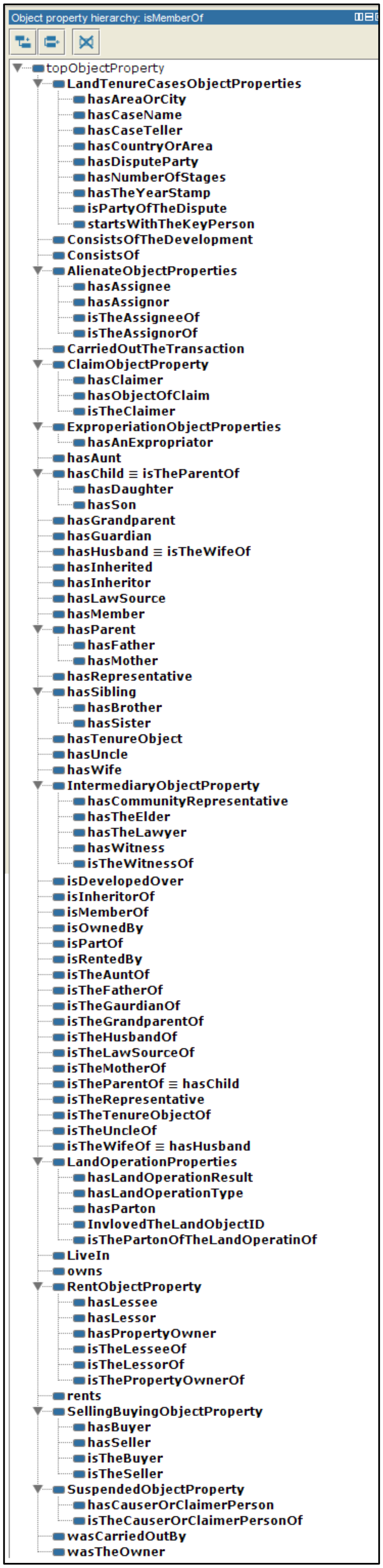

Figure C.3. TTN Object Property Relationships

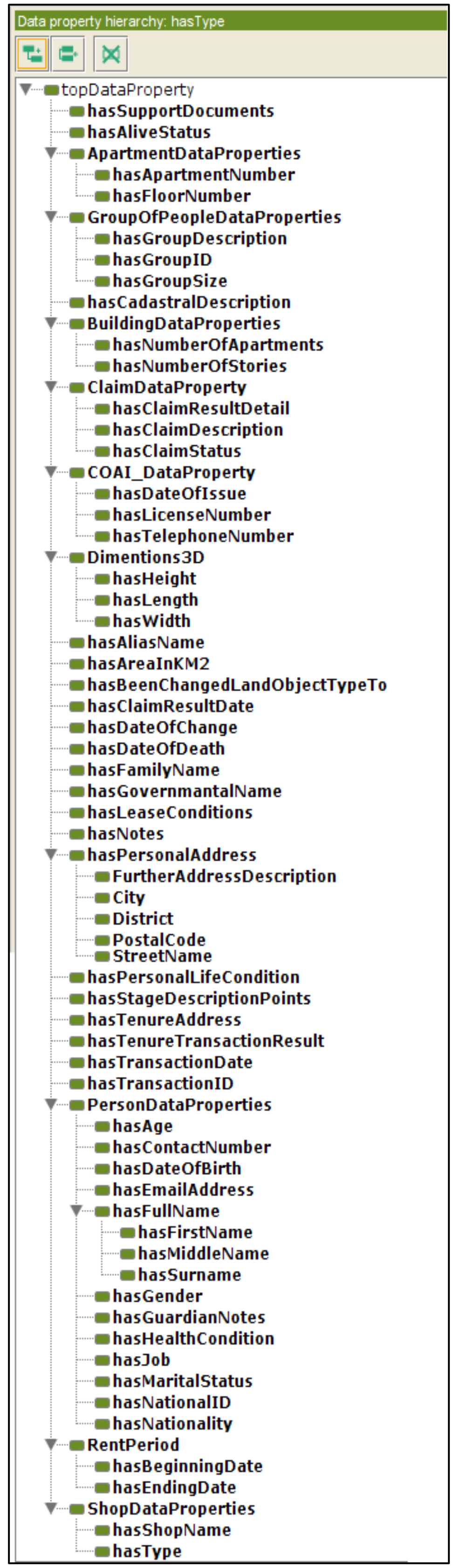

Figure C.4. TTN Data Property Relationships

As shown in figure C.3, the *topObjectProperty* relationship is the default root for the Triple Store relationships where any other relationships are sub-properties of the *topObjectProperty* relationship. The object relationships of the TTN database are described as follows:

- *AlienateObjectProperties* captures different relationships of an alienation transaction, which is transferring rights/ownership of a property from a tenant to another person. To describe an alienate transaction, an assignor and an assignee should be determined to link them with the alienate transaction. The assignor and the assignee are individuals of the *Person* class. To describe an *AlienateObjectProperties* relationship, the following sub-relationships should be established:
    - *hasAssignee* links an alienation transaction with an assignee. The assignee is an individual of the *Tenant* class.
        - The inverse of the *hasAssignee* relationship is the *isTheAssigneeOf* relationship where it links an assignee with an alienation transaction.
    - *hasAssignor* links an alienation transaction with an assignor. The assignor is an individual of the *Tenant* class.
        - The inverse of the *hasAssignor* relationship is the *isTheAssignorOf* relationship where it links an assignor with an alienation transaction.
- *CarriedOutTheTransaction* captures and describes the court which has issued a tenure transaction. The relationship links a subject from the *CourtName* class with an object from the *TenureTransaction* class. The inverse of this relationship is the *wasCarriedOutBy* relationship.
- *ClaimObjectProperty* captures different relationships related to a tenure claim transaction. Each claim transaction consists of different individuals, such as a claimer,

and a claim object (*e.g.* a house, a parcel of land, and an apartment). To describe a *ClaimObjectProperty* relationship, the following sub-relationships should be established:

- *hasClaimer* links a subject from the *Claim* class with an object, claimer, from the *Tenant* class.
    - The inverse of the *hasClaimer* relationship is the *isTheClaimer* relationship. The inverse relationship links the claimer individual as a subject with the claim individual as an object.
- *hasObjectOfClaim* links a claim transaction with a tenure object which is an individual of the *TenureObject* class.

- *ConsistsOf* links an individual from the *Building* class with an individual from one of the following classes: *Shop*, *Apartment*, or *Garage*. The inverse of the *Consists* relationship is the *isPartOf* relationship. The inverse relationship links an individual from one of the following classes: *Apartment*, *Shop*, or *Garage* with an individual from the *Building* class.
- *ConsistsOfTheDevelopment* describes a development on a parcel of land such as: building, house, shop, garage, shelter, and apartment. It links an individual from the *LandObject* class with an individual from the *Development* class. The inverse of this relationship is the *isDevelopedOver* relationship. It likes an individual from the *Development* class with an individual from the *LandObject* class.
- *ExpropriationObjectProperties* describes an expropriation case performed by a governmental institution on a tenure object. This relationship consists of *hasAnExpropriator* relationship and it links an individual from the

ExpropriationTransaction class with an individual from the *Government/Municipality[GM]* class.

- *hasAunt* describes the following types of social relationships: sister, half-sister, or a sister-in-law of a parent. This relationship links an individual from the *Person* class with a female individual from the same class. The inverse of this relationship is the *isTheAuntOf* relationship.
- *hasChild* describes a “child-ship” (offspring) relationship between two individuals, where a child has a father and a mother. On the other side of the relationship, a couple (father and mother) can have more than one child. This relationships is equivalent to the *isTheParentOf* relationship. The inverse of the *hasChild* relationship is the *hasParent* relationship. To describe the *hasChild* relationship, one of the following sub-relationships should be established:
    - *hasDaughter* links an individual from the *Mother* or the *Father* class with an individual from the *Daughter* class or a female individual from the *Person* class. The relationship is defined in a way which prevents a daughter to have more than one mother or father.
    - *hasSon* links an individual from the *Mother* or the *Father* class with an individual from the *Son* class or a male individual from the *Person* class. The relationship is defined in a way that prevents a son to have more than one mother or father.
- *hasGrandparent* describes a grandparent’s relationship with a grandchild. Figure C.5 describes this relationship. Assume *P1*, *P2*, and *P3* are individual of the *Person* class. The *hasGrandparent* relationship is defined automatically between two *P1* and *P3* if

the relationship between *P1* and *P2* is *hasParent*, and the relationship between *P2* and *P3* is *hasParent*. The inverse of this relationship is the *hasGrandparent* relationship is the *isTheGrandparentOf* relationship.

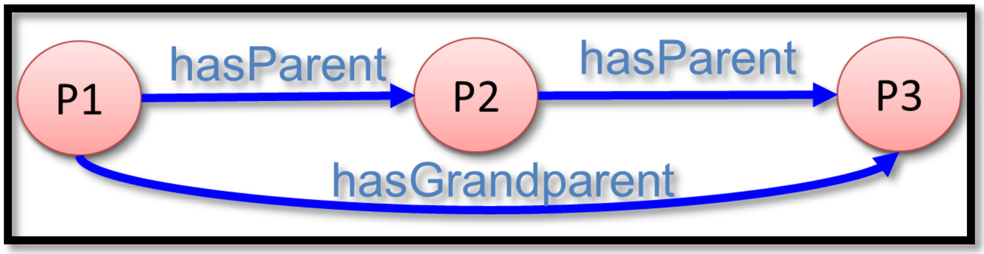

Figure C.5. *hasGrandparent* relationship

- *hasGuardian* describes a guardianship relationship between two individuals from the *Person* class. A child may have a guardian who is legally responsible to take care of the child's inherited properties. The inverse of this relationship is the *isTheGuardianOf* relationship.
- *hasHusband* links a female individual from the *Person* class with a male individual from the same class in order to describe a husband relationship with a wife. The inverse of this relationship is the *isTheWifeOf* relationship.
- *hasInherited* describes the inherited person of an inheritance transaction. It links an individual from the *InheritanceTransaction* class with an individual from the *Tenant* class.
- *hasInheritor* describes the inheritor person of an inheritance transaction. It links an individual from the *InheritanceTransaction* class with an individual from the *Person* class. The inverse of this relationship is the *isInheritorOf* relationship.
- *hasLawSource* describes the law source of a court. This relationship links an individual from the *CourtName* class with an individual from the *LawSource* class. The *isTheLawSourceOf* relationship is the inverse of the *hasLawSource* relationship.

- *hasMember* describes a family member or a group of people. It links an individual from the *Family* or the *GroupOfPeople* class with an individual from the *Person* class. The *isMemberOf* relationship is the inverse of the *hasMember* relationship.
- *hasParent* describes the relationship between a parent and a child. To describe this relationship, one of the following sub-relationships should be established:
    - *hasFather* links an individual from the *Son* or the *Daughter* class with an individual from the *Father* class. The relationship is defined in a way that prevents a daughter or a son from having more than one father. The inverse of this relationship is the *isTheFatherOf* relationship.
    - *hasMother* links an individual from the *Son* or the *Daughter* class with an individual from the *Mother* class. The relationship is defined in a way that prevents a son or a daughter from having more than one mother. The inverse of this relationship is the *isTheMotherOf* relationship.
- *hasRepresentative* describes the person who represents a constituency, a community, a government, a company, or a group of people. It links an individual one of the following classes: *Family*, *Government/Municipality[GM]*, *COAI_[Company/Organization/Association/Institution]*, or *GroupOfPeople* with an individual of the *Person* class. The inverse of this relationship is the *isTheRepresentative* relationship.
- *hasSibling* describes a sister or brother relationship. The database establishes this relationship between two individuals from the *Person* class if they have the same mother or father. This relationship consists of two sub-relationships: *hasBrother*, and *hasSister*. The database differentiates between these sub-relationships based on the

gender type of the object of the *hasSibling* relationship. If the gender type of the object of the *hasSibling* relationship is female, then the relationship will be *hasSister*. If the gender type is male, then the relationship will be *hasBrother*.

- *hasTenureObject* describes the tenure object of a tenure transaction. It links an individual from the *TenureTransaction* class with an individual from the *TenureObject* class. The inverse of this relationship is the *isTheTenureObjectOf* relationship.
- *hasUncle* is established between two individuals if one of the individuals is the brother of the father of the second individual. It links an individual from the *Person* class with an individual from the same class if the father of the first individual has a *hasBrother* relationship with the father of the second individual. The inverse of this relationship is the *isTheUncleOf* relationship.
- *hasWife* describes a spousal relationship between a couple. The two individuals of this relationship are from the *Person* class. The relationship links a husband with his wife.
- *IntermediaryObjectProperty* describes the third party (a lawyer, an elder, a community representative, and/or a witness) of a land tenure transaction. Therefore, the *IntermediaryObjectProperty* relationship consists of the following sub-relationships:
    - *hasCommunityRepresentative* links an individual from the *TenureTransaction* class with an individual from the *CommunityRepresentative* class.
    - *hasTheElder* links an individual from the *TenureTransaction* class with an individual from the *Elder* class.
    - *hasTheLawyer* links an individual from the *TenureTransaction* class with an individual from the *Lawyer* class.

- *hasWitness* links an individual from one of the following classes: *TenureTransaction*, or *LandOperations* with an individual from one of the following classes: *Person*, or *Witness*. The inverse of this relationship is the *isTheWitnessOf* relationship.

- *isOwnedBy* describes the ownership of a tenure property. It links an individual from the *TenureObject* class with an individual from the *TenantPerson* class. The inverse of this relationship is the *owns* relationship.
- *isRentedBy* describes a rent tenure relationship between a tenant and a tenure object. It links an individual from the *TenureObject* class with an individual from the *TenantPerson* class. The inverse of this relationship is the *rents* relationship.
- *LandOperationProperties* describes different types of land tenure operations: land division, merging land objects, and changing land type. To describe a land operation, the following sub-relationships should be established:
    - *InvolvedTheLandObjectID* links an individual from the *LandOperation* class with an individual from the *LandObject* class in order to determine the land object which is part of a land operation.
    - *hasLandOperationType* links an individual from the *hasLandOperationType* class with exactly one individual from the *LandOperation* class in order to describe the land operation type.
    - *hasParton* describes a person who supported and sponsored the land operation activity (*e.g.* lawyer, elder, and community representative). It links exactly one individual from the *LandOperation* class with an individual from the *Person*

class. The inverse of this relationship is the *isThePartonofTheLandOperationOf* relationship.

- *hasLandOperationResult* describes the result(s) of a land operation. It links an individual from one of the following classes: *Merge, Division, InheritanceTransaction,* or *ChangingLandObjectType* with an individual from the *LandObject* class.

- *LandTenureCases*ObjectProperties captures and briefly describes basic information about a land tenure case before getting into more detail. This relationship consists of the following sub-relationships:
  - *hasAreaOrCity* links an individual from the *CaseCountry* class with an individual from the *CaseArea* class. The relationship describes the area or the city where the disputed land object is located.
  - *hasCaseName* links an individual from the *CaseID* class with exactly one individual from the *CaseName* class. This relationship is to describe the ID of a land tenure dispute scenario.
  - *hasCaseTeller* links an individual from the *CaseID* class with an individual from the *Person* class. This relationship is to describe the person who was describing the land tenure dispute.
  - *hasCountryOrArea* links an individual from the *CaseID* class with exactly one individual from the *CaseCountry* class. This relationship is to describe the country where the disputed land object is located.
  - *hasDisputeParty* describes the persons who are parties of a land tenure dispute. It links an individual from the *CaseID* class with different individuals from the

Tenant and/or the *Person* class(s). The inverse of this relationship is the *isPartyOfTheDispute* relationship.

- *hasNumberOfStages* a land dispute level may change significantly in time. The change can be described within different phases of time. The *hasNumberOfStages* relationship describes the number of stages (phases) of a land dispute. It links an individual from the *CaseID* class with an individual from the *StageNumBasedYear* class.
- *hasTheYearStamp* links one individual from the *StageNumBasedYear* class with an individual from the *YearStamp* class. Each year stamp describes a set of events that occurred within a land dispute during an interval of years.
- *StartsWithTheKeyPerson* describes the key person of a land dispute. The person should be the most recent tenant of the disputed land. This person needs to be defined in order to find the starting point of the conflict. The *StartsWithTheKeyPerson* relationship links an individual from the *CaseID* class with an individual from the *Tenant* class.

- *LiveIn* describes the construction that the person lives in, such as building, apartment, shelter, or house. It links an object from the *Person* class with an object from one of the following classes: *Building*, *Shelter*, *Apartment*, or *House*.
- *RentObjectProperty* describes information related to a rent agreement. To describe this relationship, the following sub-relationships should be established:
  - *hasLessee* links an individual from the *RentTransaction* class with an individual from the *Person* class. The inverse of this relationship is the *isTheLesseeOf* relationship.

- *hasLessor* links an individual from the *RentTransaction* class with an individual from the *Tenant* class. The inverse of this relationship is the *isTheLessorOf* relationship. A lessor person can be the owner of the released tenure or the renter.
- *hasPropertyOwner* links an individual from the *RentTransaction* class with an individual from the *Tenant* class. The inverse of this relationship is the *isThePropertyOwnerOf* relationship. This relationship describes the ownership of a rented tenure.

- *SellingBuyingObjectProperty* describes the seller and the buyer of a *selling/buying* transaction. To describe this relationship, the following sub-relationships should be established:
    - *hasBuyer* links an individual from the *SellingBuyingTransactions* class with an individual from the *Person* class in order to describe the buyer party. The inverse of this relationship is the *isTheBuyer* relationship.
    - *hasSeller* links an individual from the *SellingBuyingTransactions* class with an individual from the *Tenant* class in order to describe the seller party. The inverse of this relationship is the *isTheSeller* relationship.
- *SuspendedObjectProperty* describes the person who is an instigate or a claimer of a suspended transaction. This relationship consists of the *hasCauserOrClaimerPerson* relationship, which links an individual from the *SuspendingTransaction* class with an individual from the *Tenant* class. The inverse of the *hasCauserOrClaimerPerson* relationship is the *isTheCauserOrClaimerPersonOf* relationship.

- *wasTheOwner* describes the last owner of a tenure object. It links an individual from the *Person* and/or *Tenant* class with an individual from the *TenureObject* class.

Regarding the data property relationship, as shown in figure C.4, data properties are listed in the same form as the object property relationship. The data property relationship describes the data value of an instance. All relationships are sub-relationships of the *topDataProperty* relationship, which is the default root of all data property relationships. The following describes the defined TTN data property relationships:

- *ApartmentDataProperties* describes two characteristics of an apartment: the unit number and the floor number. Therefore, the *ApartmentDataProperties* relationship consists of the following sub-relationships:
    - *hasApartmentNumber* links an individual from the *Apartment* class with an integer value to describe the number of an apartment inside a building.
    - *hasFloorNumber* links an individual from the *Apartment* class with an integer value to describe the floor number of an apartment.
- *BuildingDataProperties* describes the number of apartments and floors (stories) within a building. This relationship consists of the following sub-relationships:
    - *hasNumberOfApartments* links an individual from the *Building* class with an integer value to describe the number of apartments within a building.
    - *hasNumberOfStories* links an individual from the *Building* class with an integer value to describe the number of floors of a building.
- *ClaimDataProperty* describes a tenure claim. The relationship consists of the following sub-relationships:

- *hasClaimDescription* links an individual from the *Claim* class with a text in order to describe a claim context.
- *hasClaimResultDetails* links an individual from the *Claim* class with a text in order to describe the result(s) of a claim request.
- *hasClaimStatus* describes the status of a claim (accepted, in progress, or rejected). This relationship links an individual from the *Claim* class with one of the following defined values: "Accepted", "In progress", or "Rejected".

- *COAI_DataProperty* describes a registered company, organization, association, and institution. It consists of the following sub-relationships:
  - *hasDateOfIssue* links an individual from the *COAI_[Company/Organization/Association/Institution]* class with a date value to describe the data of issue of the individual.
  - *hasLicenseNumber* links an individual from the *COAI_[Company/Organization/Association/Institution]* class with an integer value to describe the license number of the individual.
  - *hasTelephoneNumber* links an individual from the *COAI_[Company/Organization/Association/Institution]* class with an integer value to describe the telephone number of the individual.
- *Dimensions3D* describes the three dimension (3D) elements of cadastral data (height, width, and length) in order to describe a 3D unit. The unit can be a garage, a shelter, or a shop. Thus, this relationship consists of the following sub-relationships:
  - *hasHight* links an individual from one of the following classes: *Garage, Shelter*, or *Shop* with a double value to describe the individual's height.

- *hasLength* links an individual from one of the following classes: *Garage*, *Shelter,* or *Shop* with a double value to describe the individual's length.
- *hasWidth* links an individual from one of the following classes: *Garage*, *Shelter,* or *Shop* with a double value to describe the individual's width.

- *hasFamilyName* links an individual from the *Family* class with a string value to describe the surname of the individual.
- *hasGovernmentalName* links an individual from the *Government/Municipality[GM]* class with a string value to describe the official name of a municipality or a governmental institution.
- *GroupOfPeopleDataProperties* describes a group of people. This relationship consists of the following sub-relationships:
    - *hasGroupDescription* provides a brief description about a group of people. It links an individual from the *GroupOfPeople* class with a string value in order to provide a description about the individual.
    - *hasGroupID* links an individual from the *GroupOfPeople* class with a short string value in order to assign an ID for the individual.
    - *hasGroupSize* links an individual from the *GroupOfPeople* class with a positive integer value. This value describes the number of member in a group (group size).
- *hasAliasName* links an individual from one of the following classes: *COAI_[Company/Organization/Association/Institution]*, *Government/Municipality[GM]*, or *GroupOfPeople* with a string value to describe the alias name of the individual.

- *hasAreaInKM^2* links an individual from the *TenureObject* class with a positive integer value to describe the area of the individual in meter square unit.
- *hasBeenChangedLandObjectTypeTo* describes the recent land type of a parcel of land after changing its previous type. It links an individual from the *ChangingLandObjectType* class with one of the following defined land types: “Governmental Land”, “Industry Land”, “Israeli Buffer Zone”, “Israeli Settlement Land”, “Living”, “Private”, “Public”, or “Waqf.”
- *hasCadastralDescription* provides the cadastral description of a land object. It links an individual from the *TenureObject* class with a string value.
- *hasClaimResultData* links an individual from the *Claim* class with a date value to describe the date of releasing claim transaction’s results.
- *hasDateOfChange* links an individual from the *LandOperation* class with a date value to describe the date of a change operation transaction.
- *hasDateOfDeath* describes the date of a person’s death. It links an individual from the *Person* class with a date value.
- *hasAliveStatus* links an individual from the *Person* class with one of the following defined values: “Alive”, or “Dead” to describe the live status of a person.
- *hasLeaseConditions* describes the conditions of a rent transaction. It links an individual from the *RenTransaction* class with a sting value.
- *hasNotes* links an individual from one of the *LTIS* classes with a string value to describe some notes.
- *hasPersonalAddress* describes the home address of a person. It consists of the following sub-relationships:

- *City* describes the name of the city component of an address. It links an individual from the *Person* class with a short string value.
- *District* describes the name of the district component of an address. It links an individual from the *Person* class with a short string value.
- *FurtherAddressDescription* describes any needed further description of a personal address. It links an individual from the *Person* class with a string value.
- *PostalCode* describes the postal code of a personal address. It links an individual from the *Person* class with a short string value.
- *StreetName* describes the street name of a personal address. It links an individual from the *Person* class with a short string value.

- *hasPersonalLifeCondition* describes the living condition of a person (if the person is a free person, a captive, or an exile). It links an individual from the *Person* class with one of the following defined values: "A Free person", "Captive", or "Exiled."
- *hasStageDescriptionPoints* describes a land scenario during a specific interval of time. It links an individual from the *YearStamp* class with a string value.
- *hasSupportedDocuments* describes supported documents (*e.g.* deeds, scanned documents, video, notes, and pictures) that are related to a land object. It links an individual from the *TenureTransaction* class with a hyperlink that connect a land tenure transaction with its supported documents.
- *hasTenureAddress* links an individual from the *TenureObject* class with a string value to describe the spatial address of a tenure object.

- *hasTenureTransactionResult* describes the generated results of a submitted tenure transaction. It links an individual from the *Claim* class with a string value to describe the results.
- *hasTransactionDate* describes the submission date of a tenure transaction. It links an individual from the *TenureTransaction* class with a date value.
- *hasTransactionID* links an individual from the *TenureTransaction* class with a string value to describe an ID for the individual.
- *PersonDataProperties* this relationship describes personal information of an individual. This relationships consists of the following sub-relationships:
    - *hasAge* describes the age of a person. It links an individual from the *Person* class with an integer number.
    - *hasContactNumber* describes the contact number (*e.g.* a mobile, or a landline phone) of a person. It links an individual from the *Person* class with an integer number.
    - *hasDateOfBirth* describes the date of birth of a person. It links an individual from the *Person* class with a date value.
    - *hasEmailAddress* describes the email address of a person. It links an individual from the *Person* class with a short string value.
    - *hasFullName* this relationship describes the full name (first name, middle name, and last name) of a person. To describe the full name of a person, the following sub-relationships should be established:
        - *hasFirstName* describes the first name of a person. It links an individual from the *Person* class with a short string value.

    - *hasMiddleName* describes the middle name of a person. It links an individual from the *Person* class with a short string value.
    - *hasSurname* describes the surname of a person. It links an individual from the *Person* class with a short string value.
- *hasGender* describes the gender type of a person. It links an individual from the *Person* class with one of following values: “Female”, “Male”, or “Unknown.”
- *hasGuardianNotes* describes explains the reasons of why a specific individual has a guardian person. For example, the individual’s age is less than 18. It links an individual from the *Person* class with a string value.
- *hasHealthCondition* describes the health condition of a person. It links an individual from the *Person* class with one or more of the following defined values: “Chronic Disease”, “Disabled”, and/ or “Normal.”
- *hasJob* describes the job of a person. It links an individual from the *Person* class with a string value.
- *hasMaritalStatus* describes the marital status of a person. It links an individual from the *Person* class with one of the following defined values: “Married”, “Single”, or “Widow.”
- *hasNationalID* describes the national Identification of a person. It links an individual from the *Person* class with a short string value.
- *hasNationality* describes the nationality of a person. It links an individual from the *Person* class with a short string value.

- *RentPeriod* describes the period time of a rent transaction: the activation date and the expiration dates. To describe the interval time of a rent transaction, the following sub-relationships should be established:
    - *hasBeginningDate* describes the activation date of a rent transaction. It links an individual from the *RentTransaction* with a date value.
    - *hasEndingDate* describes the expiration date of a rent transaction. It links an individual from the *RentTransaction* with a date value.
- *ShopDataProperties* describes the characteristics of a shop, such as the shop type (*e.g.* grocery, salon, clothes shop, etc.) and the name. It consists of the following sub-relationships:
    - *hasShopName* links an individual from the *Shop* class with a string value to describe the name of the individual (shop).
    - *hasType* describes the type of a shop. It links an individual from the *Shop* class with one or more of the following defined values: "Accounting Office", "Clothes", "Coffee Shop", "Computers", "Electrical Tools", "Grocery", "Hair Salon", "Internet Café", "Mobile Phones", "Money Exchange", "Paint", "Photo Shop", "Poultry", "Real Estate Office", "Restaurant", "Stationery Shop", and/or "Barber Shop". This relationship is developed in a way that allows a user to change (add, delete, and edit) these values easily.

Regarding the domain and the range of the defined TTN relationships, tables C.1 and C.2 describe the domain(s), the range(s), and the characteristics of the object property and the data property relationships, respectively.

Table C.1. The domain, range, and characteristic(s) of each Object property relationship:

Object property relationships:			
Relationship	**Domain**	**Range**	**Characteristics**
hasAssignee	*AlienateTransaction*	*Tenant*	• Asymmetric • Irreflective
hasAssignor	*AlienateTransaction*	*Tenant*	• Asymmetric • Irreflective
isTheAssigneeOf	*Tenant*	*AlienateTransaction*	• Inverse functional • Asymmetric • Irreflective
isTheAssignorOf	*Tenant*	*AlienateTransaction*	• Inverse functional • Asymmetric

			• Irreflective
CarriedOutTheTransaction	*CourtName*	*TenureTransaction*	• Irreflective
hasClaimer	*Claim*	*Tenant*	• Asymmetric • Irreflective
hasObjectOfClaim	*Claim*	*TenureObject*	• Asymmetric
isTheClaimer	*Tenant*	*Claim*	• Asymmetric • Irreflective
ConsistsOf	*Building*	▪ *Shop* ▪ *Apartment* ▪ *Garage*	• Transitive
ConsistsOfTheDevelopment	*LandObject*	*Development*	• Transitive

hasAnExpropriator	*ExpropriationTransaction*	*Government/Municipality* *[GM]*	• Functional • Asymmetric • Irreflective
hasAunt	*Person*	*Person*	-
isTheAuntOf	*Person*	*Person*	-
hasChild	▪ *Mother* ▪ *Father*	*Person*	• Asymmetric • Irreflective
hasDaughter	*Parent*	*Daughter*	• Asymmetric • Irreflective
hasSon	*Parent*	*Son*	• Asymmetric • Irreflective
hasGrandparent	*Person*	*Person*	-
hasGuardian	*Person*	*Person*	• Functional

			• Asymmetric • Irreflective
hasHusband	*Person*	*Person*	• Functional • Asymmetric • Irreflective
hasInherited	*InheritanceTransaction*	*Tenant*	• Asymmetric • Irreflective
hasInheritor	*InheritanceTransaction*	*Person*	• Asymmetric • Irreflective
hasLawSource	*CourtName*	*LawSource*	• Irreflective
hasMember	▪ *Family* ▪ *GroupOfPeople*	*Person*	• Asymmetric • Irreflective
hasParent	*Person*	*Person*	• Asymmetric • Irreflective

hasFather	*Person*	*Father*	• Asymmetric • Irreflective
hasMother	*Person*	*Mother*	• Asymmetric • Irreflective
hasRepresentative	▪ *Family* ▪ *Government/Municipality[GM]* ▪ *COAI_[Company/Organization/Association/Institution]* ▪ *GroupOfPeople*	*Person*	• Asymmetric
hasSibling	*Person*	*Sibling*	• Transitive • Symmetric
hasBrother	*Person*	*Person*	-
hasSister	*Person*	*Person*	-

hasTenureObject	*TenureTransaction*	*TenureObject*	• Asymmetric
hasUncle	*Person*	*Person*	-
hasWife	*Person*	*Person*	• Asymmetric • Irreflective
hasCommunityRepresentative	*TenureTransaction*	*CommunityRepresentative*	• Functional
hasTheElder	*TenureTransaction*	*Elder*	• Functional
hasTheLawyer	*TenureTransaction*	*Lawyer*	• Functional
hasWitness	▪ *TenureTransaction* ▪ *LandOperation*	▪ *Person* ▪ *Witness*	• Irreflective
isTheWitnessOf	▪ *Person* ▪ *Witness*	▪ *TenureTransaction* ▪ *LandOperation*	• Irreflective
isDevelopedOver	*Development*	*LandObject*	• Transitive

isInheritorOf	*Person*	*InheritanceTransaction*	• Asymmetric • Irreflective
isMemberOf	*Person*	▪ *Family* ▪ *GroupOfPeople*	• Asymmetric • Irreflective
isOwnedBy	*TenureObject*	*TenantPerson*	• Asymmetric • Irreflective
isPartOf	▪ *Garage* ▪ *Apartment* ▪ *Shop*	*Building*	• Transitive
isRentedBy	*TenureObject*	*TenantPerson*	• Asymmetric • Irreflective
isTheFatherOf	*Father*	*Person*	• Irreflective

isTheGaurdianOf	*Person*	*Person*	• Inverse functional • Asymmetric • Irreflective
isTheGrandparentOf	*Person*	*Person*	-
isTheHusbandOf	*Person*	*Person*	• Inverse functional • Asymmetric • Irreflective
isTheLawSourceOf	*LawSource*	*CourtName*	• Irreflective
isTheMotherOf	*Mother*	*Person*	• Inverse functional • Irreflective

isTheParentOf	-	-	• Equivalent to "hasChild"
isTheRepresentative	*Person*	▪ *Family* ▪ *Government/Municipality[GM]* ▪ *COAI_[Company/Organization/Association/Institution]* ▪ *GroupOfPeople*	• Asymmetric • Irreflective
isTheTenureObjectOf	*TenureObject*	*TenureTransaction*	-
isTheUncleOf	*Person*	*Person*	-
isTheWifeOf	*Person*	*Person*	• Asymmetric • Irreflective

hasLandOperationResult	▪ *Merge* ▪ *Division* ▪ *InheritanceTransaction* ▪ *ChangingLandObjectType*	*LandObject*	• Irreflective
hasLandOperationType	*LandObject*	*LandOperation*	• Functional
hasParton	*LandOperation*	*Person*	• Irreflective
InvolvedTheLandObjectID	*LandOperation*	*LandObject*	-
isThePartonOfTheLandOperationOf	*Person*	*LandOperation*	• Irreflective
hasAreaOrCity	*CaseCountry*	*CaseArea*	-
hasCaseName	*CaseID*	*CaseName*	-
hasCaseTeller	*CaseID*	*Person*	-

hasCountryOrArea	*CaseID*	*CaseCountry*	-
hasDisputeParty	*CaseID*	▪ *Tenant* ▪ *Person*	-
hasNumberOfStages	*CaseID*	*StagesNumBasedYear*	• Functional;
hasTheYearStamp	*StagesNumBasedYear*	*YearStamp*	• Functional
isPartyOfTheDispute	▪ *Tenant* ▪ *Person*	*CaseID*	-
startsWithTheKeyPerson	*CaseID*	*Tenant*	-
LiveIn	*Person*	▪ *Building* ▪ *Shelter* ▪ *Apartment* ▪ *House*	-
owns	*TenantPerson*	*TenureObject*	• Asymmetric

			• Irreflective
hasLessee	*RentTransaction*	*Person*	• Functional • Asymmetric • Irreflective
hasLessor	*RentTransaction*	*Tenant*	• Functional • Asymmetric • Irreflective
hasPropertyOwner	*RentTransaction*	*Tenant*	• Functional • Asymmetric • Irreflective
isTheLesseeOf	*Person*	*RentTransaction*	• Inverse functional • Asymmetric • Irreflective

isTheLessorOf	*RentTransaction*	*Tenant*	• Inverse functional • Asymmetric • Irreflective
isThePropertyOwnerOf	*Tenant*	*RentTransaction*	• Inverse functional • Asymmetric • Irreflective
rents	*TenantPerson*	*TenureObject*	• Asymmetric • Irreflective
hasBuyer	*SellingBuyingTransaction*	*Person*	• Functional • Asymmetric • Irreflective
hasSeller	*SellingBuyingTransaction*	*Tenant*	• Functional

			• Asymmetric • Irreflective
isTheBuyer	*Person*	*SellingBuyingTransaction*	• Inverse functional • Asymmetric • Irreflective
isTheSeller	*Tenant*	*SellingBuyingTransaction*	• Inverse functional • Asymmetric • Irreflective
hasCauserOrClaimerPerson	*SuspendingTransaction*	*Tenant*	• Functional • Asymmetric • Irreflective

isTheCauserOrClaimerPersonOf	*Tenant*	*SuspendingTransaction*	• Inverse functional • Asymmetric • Irreflective
wasCarriedOutBy	*TenureTransaction*	*CourtName*	• Irreflective
wasTheOwner	▪ *Person* ▪ *Tenant*	*TenureObject*	-

Table C.2. The domain, range, and characteristic(s) of each Data property relationship:

Data property relationships:			
Relationship	**Domain**	**Range**	**Characteristics**
hasApartmentNumber	*Apartment*	int	• Functional
hasFloorNumber	*Apartment*	int	• Functional

hasNumberOfApartments	*Building*	int	• Functional
hasNumberOfStories	*Building*	int	• Functional
hasClaimDescription	*Claim*	string	• Functional
hasClaimResultDetails	*Claim*	string	• Functional
hasClaimStatus	*Claim*	"Accepted", "In Progress", or "Rejected"	• Functional
hasDateOfIssue	*COAI_[Company/Organization/Association/Institution*	dateTime	• Functional
hasLicenseNumber	*COAI_[Company/Organization/Association/Institution*	integer	• Functional
hasTelephoneNumber	*COAI_[Company/Organization/Association/Institution*	integer	• Functional
hasHight	▪ *Garage*	double	• Functional

	▪ *Shelter* ▪ *Shop*		
hasLength	▪ *Garage* ▪ *Shelter* ▪ *Shop*	double	• Functional
hasWidth	▪ *Garage* ▪ *Shelter* ▪ *Shop*	double	• Functional
hasGroupDescribtion	*GroupOfPeople*	string	• Functional
hasGroupID	*GroupOfPeople*	short	• Functional
hasGroupSize	*GroupOfPeople*	positiveInteger	• Functional

hasAliasName	▪ *COAI_[Company/Organization/Association/Institution* ▪ *Government/Municipality[GM]* ▪ *GroupOfPeople*	string	• Functional
hasAreaInKM2	*TenureObject*	positiveInteger	• Functional
hasBeenChangedLandObjectTypeTo	*ChangingLandObjectType*	“Governmental Land”, “Industry Land”, “Israeli Buffer Zone”, “Israeli Settlement Land”, Living”, “Private”, “Public”, or “Waqf”	• Functional
hasCadastralDescribtion	*TenureObject*	string	• Functional
hasClaimResultDate	*Claim*	dateTime	• Functional
hasDateOfChange	*LandOperation*	dateTime	• Functional

hasDateOfDeath	*Person*	dateTime	• Functional
hasFamilyName	*Family*	string	• Functional
hasGovernmentalName	*Government/Municipality[GM]*	string	• Functional
hasAliveStatus	*Person*	“Alive”, or “Dead”	• Functional
hasLeaseCondition	*RentTransaction*	string	• Functional
hasNotes	*LTIS*	sting	• Functional
City	*Person*	short	• Functional
District	*Person*	short	• Functional
FurtherAddressDescribtion	*Person*	string	• Functional
PostalCode	*Person*	short	• Functional
StreetName	*Person*	short	• Functional

hasPersonalLifeCondition	*Person*	"A Free Person", "Captive", or "Exiled"	• Functional
hasStageDescribtionPoints	*YearStamp*	string	-
hasSupportedDocuments	*TenureTransaction*	anyURI	• Functional
hasTenureAddress	*TenureObject*	string	• Functional
hasTenureTransactionResult	*Claim*	anyURI, or string	• Functional
hasTransactionDate	*TenureTransaction*	dateTime	• Functional
hasTransactionID	*TenureTransaction*	string	• Functional
has Age	*Person*	int	• Functional
hasContactNumber	*Person*	long	• Functional
hasDateOfBirth	*Person*	dateTime	• Functional
hasEmailAddress	*Person*	short	• Functional

hasFullName	*Person*	short	-
hasFirstName	*Person*	short	• Functional
hasMiddleName	*Person*	short	• Functional
hasSurname	*Person*	short	• Functional
hasGender	*Person*	"Female", "Male", or "Unknown"	• Functional
hasGaurdianNotes	*Person*	string	• Functional
hasHealthCondition	*Person*	"Chronic Disease", "Disabled", and/or "Normal"	-
hasJob	*Person*	short	• Functional
hasMaritalStatus	*Person*	"Married", "Single", or "Widow"	• Functional

hasNationalID	*Person*	short	• Functional
hasNationality	*Person*	short	• Functional
hasBeginningDate	*RentTransaction*	dateTime	• Functional
hasEndingDate	*RentTransaction*	dateTime	• Functional
hasShopName	*Shop*	string	-
hasType	*Shop*	“Accounting Office”, “Clothes”, “Coffee Shop”, “Computers”, “Electrical Tools”, “Grocery”, “Hair Salon”, “Internet Café”, “Mobile Phones”, “Money Exchange”, “Paint”, “Photo Shop”, “Poultry”, “Real Estate Office”,	-

		“Restaurant”, “Stationery Shop”, and/or “Barber Shop”	

Appendx D: Describing asymmetric relationships using TTS

This appendix discusses how the TTS database describes asymmetric tenure relationships in the Somaliland scenario (see Appendix B, section B.3).

As described in the scenario, Hoda is the daughter of the parents, Dema and Taher. In addition, Hoda is the mother of Ihsan. The relationships between Hoda and her parent, and Hoda and her daughter are asymmetric, which means that the relationship from Hoda to Dema is not the same as from Dema to Hoda. Hoda is the daughter of Dema, and Dema is the mother of Hoda. Considering the way that the TTS is configured, TTS described the relationship from Hoda and Dema as the same as from Dema to Hoda without describing who is the mother and the daughter. Figure D.1 depicts how the TTS described the social relationships of Hoda. As shown in figure D.1, the type of “Parent/Daughter” relationship is illustrated between Hoda and Taher Ghandy; Hoda and Dema Ghandy; and Hoda and Ihsan Dareed. This description is not enough for stakeholders to determine the mother, the father, and the daughter of Hoda. Thus, it could be challenging for a decision maker to understand the social relationship of Hoda, and this would be more confusion if Hoda had many daughters. However, TTS provides a higher level of flexibility compared to other LTISs because the TTS configuration can be changed from the Look Up table to suit specific needs.

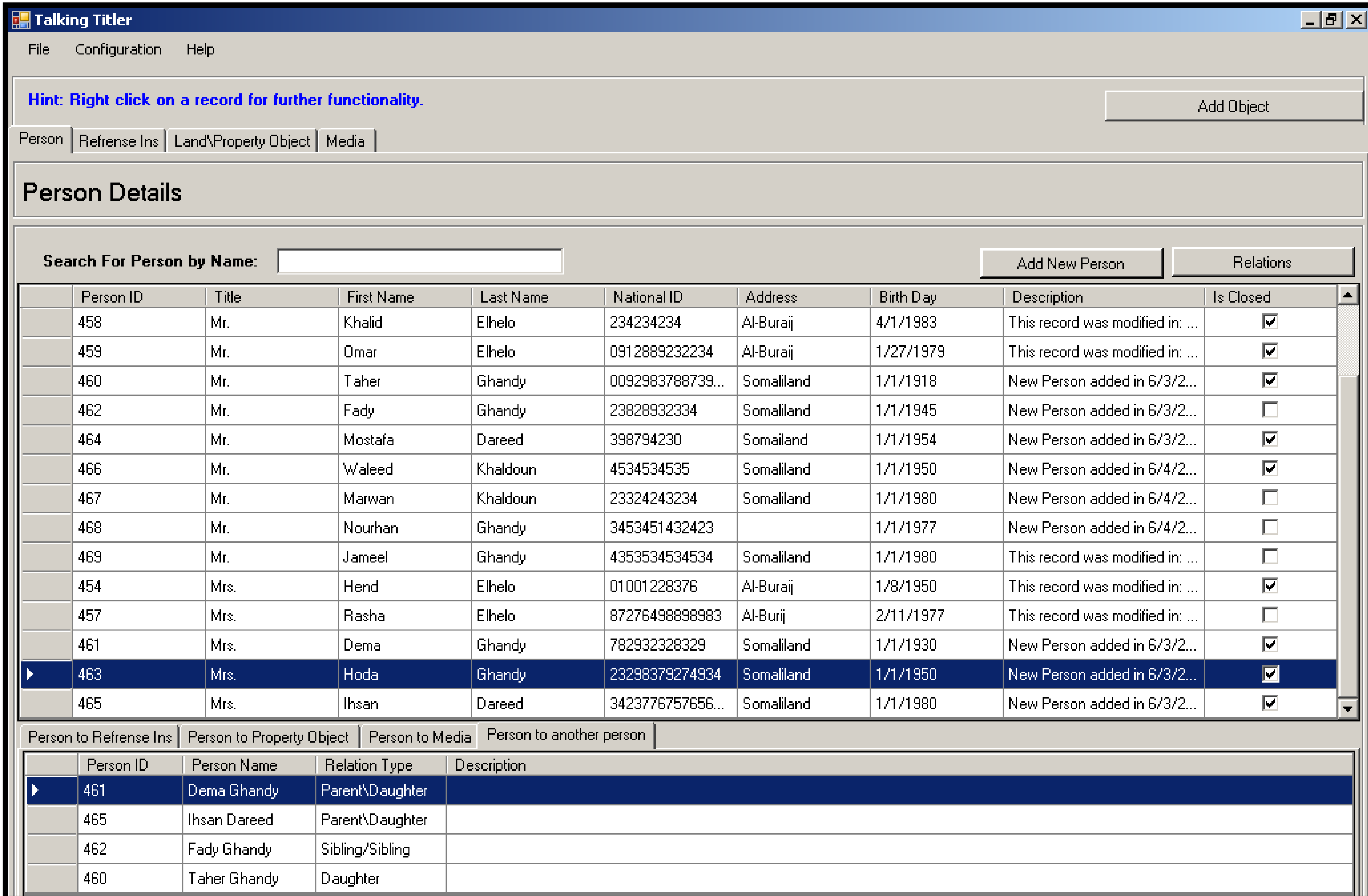

Figure D.1. Asymmetric Tenure Relationships descriptions in TTS