PROGRAMA DE DOCTORADO EN INGENIERÍA DE LA CONSTRUCCIÓN

TESIS DOCTORAL

VULNERABILIDAD URBANA, NUEVA CARACTERIZACIÓN Y METODOLOGÍA PARA EL DISEÑO DE ESCENARIOS ÓPTIMOS

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"If collective action can be employed to address threats, or to take advantage of opportunities, then the vulnerability can be mitigated and outweighed by the benefits"

Bar-Yam

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Resumen

La vulnerabilidad urbana es un problema a cuya solución la planificación estratégica urbana puede realizar una importante contribución, y cuya evaluación ha despertado un interés creciente en diferentes países. En España, este interés ha cristalizado en forma de Observatorio de Vulnerabilidad Urbana, donde se ofrece una evaluación que clasifica barrios en vulnerables o no vulnerables de acuerdo a tres indicadores básicos. Esta evaluación, sin embargo, no se ajusta aún a los requisitos actuales en materia de planificación estratégica, dificultando así su implementación en este tipo de procesos y haciendo necesaria su actualización.

La tendencia actual en planificación estratégica urbana se caracteriza por una serie de atributos que han sido objeto de desigual interés por parte de la comunidad científica, dando lugar a diferentes grados de avance en los métodos con los que implementarlos. Estos métodos tienen por objetivo posibilitar el empleo de enfoques cognitivos, e incorporar procesos participativos en el diseño de estrategias como medio de legitimarlas y para captar las preferencias de los diferentes interesados. También persiguen modelizar la naturaleza dinámica y multi-escala de los aspectos tanto temporales como político-administrativos que afectan a los problemas de planificación propios de este campo. La capacidad estratégica es, así mismo, otra cualidad demandada, para lo cual el empleo de enfoques multi-objetivo ofrecen una alternativa válida a la hora de localizar estrategias con las que hacer frente a los diversos problemas que acucian a nuestra sociedad.

Toda estrategia, además, cifra buena parte de sus posibilidades de éxito en una correcta apreciación de las circunstancias que la rodean lo cual, por otro lado, la hace dependiente de las incertidumbres asociadas. En el ámbito de la planificación estratégica urbana, la creciente necesidad de incorporar estas incertidumbres a los procesos decisionales ha marcado la evolución que ha experimentado dicho campo, dando lugar al desarrollo de diferentes métodos de evaluación basados en la generación de escenarios y el análisis de alternativas bajo estos supuestos. Estos métodos analizan el comportamiento de diferentes estrategias a lo largo de un conjunto de escenarios que pueden ser óptimos o pésimos, pero no ambos. Esta laguna supone una limitación a la hora de identificar estrategias a la vez robustas frente a los escenarios más adversos, y sensibles frente a los más favorables. Entre estas técnicas, además, no figura ningún intento por incorporar la incertidumbre relacional, característica en sistemas de infraestructura implementados a lo largo de diferentes escalas político-administrativas.

Esta investigación propone solucionar dichas carencias mediante un sistema de soporte decisional integrado por diversos módulos que, en sintonía con los atributos actualmente exigibles a toda herramienta de planificación estratégica, cubra el proceso decisional completo. Partiendo de la selección de un modelo apropiado de evaluación de vulnerabilidad urbana, el sistema propuesto genera alternativas de planificación con las que hacerla frente, y permite seleccionar aquella que ofrezca un balance adecuado de riesgos y oportunidades. Así mismo, al final del proceso se ofrece un conjunto óptimo de medidas, en forma de sistema relacional, con las que acompañar la implementación de la alternativa

elegida a través del tejido político-administrativo de un territorio.

Como consecuencia, es de esperar que la aplicación de la metodología propuesta contribuya a una mejor distribución de los importantes recursos movilizados para reducir la vulnerabilidad urbana y mejorar la resiliencia. Además, el sistema decisional está compuesto por una serie de métodos de caracterización, propuesta de alternativas y evaluación de incertidumbres, aplicables a problemas similares que puedan resultar de interés en el campo de la planificación estratégica urbana.

Abstract

Urban vulnerability is a problems whose evaluation has aroused growing interest in different countries, and to whose solution urban strategic planning can render important contributions. This interest, in Spain, crystallized in the Urban Vulnerability Observatory, allowing neighborhoods to be classified as vulnerable or non-vulnerable according to three basic indicators. This evaluation does not meet, however, the requirements curently demanded by strategic planning, which makes it inadequate for its implementation into strategic planning processes, making it necessary to update it.

The current trend in urban strategic planning is characterized by a series of attributes that have been object of unequal interest on the part of the scientific community, giving rise to different degrees of progress in the methods with which to implement them. These methods are intended to afford cognitive approaches, and incorporate participatory processes in the design of strategies as a means of legitimizing them and to capture preferences of the different stakeholders. They also seek to model the dynamic and multi-scale nature of both temporal and political-administrative aspects that affect the planning problems relating this field. The strategic capacity is, likewise, another quality demanded, for which the use of multi-objective approaches offer a valid alternative when it comes to locating strategies with which to deal with the real-world problems that beset our society.

Besides, whatever the strategy we analize its chances for succes relies, to a large extent, on the propper appreciation of the circumstances surrounding it which, on the other hand, makes it dependent of the uncertainties associated to the problem at stake. In the field of urban strategic planning, the growing need to address these uncertainties by incorporating them into decision-making processes, has marked the evolution of this field. As a consequence, different evaluation methods have been developed based on the generation of scenarios and the analysis of alternatives under these assumptions. These methods analyze the behavior of different strategies along a set of scenarios focused on worst or best cases, but not on both. This gap is a limitation when seeking strategies being simultaneously robust against the most adverse scenarios, and sensitive to the most favorable ones. Among these techniques, on the other hand, there is no attempt to incorporate the relational uncertainty, characteristic of infrastructure systems implemented along different political-administrative scales.

This research proposes to solve these deficiencies through a decisional support system composed of various modules that, in line with the attributes currently required by any strategic planning tool, cover the entire decisional process. Based on the selection of an appropriate urban vulnerability assessment model, the proposed decisión framework generates planning alternatives with which to address urban vulnerability, and allows selecting the one that offers an adequate balance of risks and opportunities. Likewise, at the end of the process an optimal set of policy measures, in the form of a system of relational contracts, is offered with which to accompany the implementation of the chosen alternative through the multiple political-administrative scales of a territory.

As a consequence, it is expected that the application of the proposed methodology to real decisión-making contributes to a better distribution of the important resources mobilized to reduce urban vulnerability and improve resilience. In addition, the decision system integrates a set of methods for evaluating concepts, generation of planning alternatives and evaluation of uncertainties, that are applicable to similar problems that may be of interest in the field of urban strategic planning.

Resum

La vulnerabilitat urbana és un probleme a la solució la planificació estratègica urbana pot realitzar una important contribució, de manera que la seva avaluació ha despertat un interès creixent en diferents països. A Espanya, aquest interès ha cristal·litzat en forma de Observatori de Vulnerabilitat Urbana, on s'ofereix una avaluació que permet classificar barris en vulnerables o no vulnerables d'acord a tres indicadors bàsics. Aquesta avaluació, però, no s'ajusta encara als requisits actuals en matèria de planificació estratègica, dificultant així la seva implementació en aquest tipus de processos i fent necessària la seva actualització.

Juntament amb l'apreciació d'incerteses, la tendència actual en planificació estratègica urbana es caracteritza per una sèrie d'atributs que han estat objecte de desigual interès per part de la comunitat científica, donant lloc a diferents graus d'avanç en els mètodes amb els quals implementar-los. Aquests mètodes tenen per objectiu possibilitar l'ocupació d'enfocaments cognitius, i incorporar processos participatius en el disseny d'estratègies com a mitjà de legitimar-i per captar preferències dels diferents interessats. També persegueixen modelitzar la naturalesa dinàmica i multi-escala dels aspectes tant temporals com politicoadministratius que afecten els problemes de planificació propis d'aquest camp. La capacitat estratègica és, així mateix, una altra qualitat demandada, per la qual cosa l'ocupació d'enfocaments multi-objectiu ofereixen una alternativa vàlida a l'hora de localitzar estratègies amb què fer front als problemes que apressen a la nostra societat.

Tota estratègia xifra, en gran mesura, les seves possibilitats d'èxit en una correcta apreciació de les circumstàncies que l'envolten la qual cosa, d'altra banda, es pot veure seriosament compromès per les incerteses associades. En l'àmbit de la planificació estratègica urbana, la creixent necessitat d'incorporar aquestes incerteses als processos de decisió ha marcat l'evolució que ha experimentat aquest camp, donant lloc al desenvolupament de diferents mètodes d'avaluació basats en la generació d'escenaris i l'anàlisi d'alternatives sota aquests supòsits.

D'altra banda, els mètodes d'avaluació d'incertesa esmentats analitzen el comportament de diferents estratègies al llarg d'un conjunt d'escenaris que poden ser òptims, o pèssims, però no ambdós. Aquesta llacuna suposa una limitació a l'hora d'identificar estratègies robustes enfront dels escenaris més adversos, i sensibles davant els més favorables. Entre aquestes tècniques, d'altra banda, no figura cap intent per incorporar la incertesa relacional, característica en sistemes d'infraestructura implementats al llarg de diferents escales politicoadministratives.

Aquesta investigació proposa solucionar aquestes mancances mitjançant un sistema de suport decisional integrat per diversos mòduls que, en sintonia amb els atributs actualment exigibles a tota eina de planificació estratègica, cobreixi el procés de decisió complet. Partint de la selecció d'un model apropiat d'avaluació de vulnerabilitat urbana, el sistema proposat genera alternatives de planificació amb què combatre-la, i permet seleccionar aquella que ofereixi un balanç adequat de riscos i oportunitats. Així mateix, al final del procés s'ofereix

un conjunt òptim de mesures, en forma de sistema relacional, amb les quals acompanyar la implementació de l'alternativa escollida a través del teixit politicoadministratiu d'un territori.

Com a conseqüència, és d'esperar que l'aplicació de la metodologia proposada contribueixi a una millor distribució dels importants recursos mobilitzats per reduir la vulnerabilitat urbana i millorar la resiliència. A més, el sistema de decisió planteja un conjunt de mètodes de caracterització, proposta d'alternatives i avaluació d'incerteses, aplicables a problemes similars que puguin resultar d'interès en el camp de la planificació estratègica urbana.

Capítulo 1

Introducción

Introducción

1.1. Antecedentes

La planificación estratégica, en el ámbito de las infraestructuras urbanas, ha evolucionado y con ellas los objetivos perseguidos, que han recorrido un largo trayecto en la escala evolutiva. Desde los dominantes a principios del siglo veinte, como apoyo en la estabilización de la economía y la lucha contra el desempleo enmarcados en las teorías keynesianas posteriores a la Gran Depresión, hasta sus objetivos actuales. Estos últimos pretenden extender el análisis más allá del resultado examinando los procesos mismos con el fin de extraer un conocimiento que, añadido al resultado, permita incrementar su robustez frente a la incertidumbre. Al mismo tiempo, buscan incorporar de algún modo a los diferentes agentes involucrados, integrar la planificación sobre la que se actúa con aquellas con las que esté relacionada, y proveerla de la legitimidad y confianza que, cada vez más, demanda la sociedad afectada (Malekpour et al., 2015; Munda, 2004).

Este nuevo enfoque, en el que cobra importancia el método frente al resultado, precisa de algún mecanismo que le aporte gobernanza (Adger, 2006) o capacidad estratégica (Giezen et al, 2015), controlando el balance entre los diferentes objetivos perseguidos, los cuales no necesariamente han de converger. Mecanismos de esta naturaleza ya han sido empleados, en forma de aproximación cognitiva, a la hora de controlar procesos destinados a proveer a los decisores tanto de alternativas realistas y eficaces como de criterios bajo los cuales examinarlas (Yepes et al, 2015).

Uno de los principales objetivos perseguidos por las últimas tendencias en materia de planificación estratégica urbana, es reforzar la resiliencia de las ciudades (Brugmann, 2012; Malekpour et al., 2015; Chelleri et al, 2015). Resiliencia y vulnerabilidad guardan entre si una fuerte correlación, de signo negativo (Adger, 2006; Carreño et al, 2012). En consecuencia y toda vez que es interés de los gobiernos mejorar sus niveles de resiliencia, la vulnerabilidad ha resultado ser un indicador válido cuya aplicación está siendo implementada en Alemania, y su uso incrementado en países como los Estados Unidos de América, Reino Unido, España, Latino América, Australia, Filipinas y otros países del mundo (Fekete, 2009).

***L1 Laguna de conocimiento 1**, Es necesario incorporar los modelos de evaluación de vulnerabilidad urbana a las tendencias actuales en planificación estratégica urbana:*
La vulnerabilidad puede entenderse como el grado en el que un sistema es susceptible, e incapaz de sobreponerse, a las tensiones adversas producidas por su entorno (Adger, 2006). Caracterizar y medir este concepto no es sencillo, como lo demuestra el elevado número de intentos realizados, su divergencia tanto en los objetivos perseguidos como en cuanto a los fenómenos considerados para explicarla, y la cantidad de **retos aún pendientes** (Adger, 2006). Estos últimos, apuntan hacia mejorar la robustez de los modelos, dotarlos de la capacidad de incorporar percepciones de vulnerabilidad y riesgo, de una cierta gobernabilidad y a la detección de causas relacionadas con la aparición y persistencia de la

vulnerabilidad, como las líneas de investigación futuras hacia las que deben encaminarse las propuestas de caracterización. **Estas propuestas deben converger, de algún modo, con las tendencias vanguardistas en el ámbito de la planificación estratégica urbana** (Malekpour et al., 2015; Giezen et al, 2015).

En España, el interés en el uso de la vulnerabilidad como índice de referencia ha cristalizado en la creación del Observatorio de Vulnerabilidad Urbana por parte del Ministerio de Fomento, Gobierno de España. La descripción de este concepto, así como la metodología empleada para su actual caracterización, se encuentran reflejados en los Informes Generales de Vulnerabilidad Urbana de los años 1991, 2001 y 2006 (Ministerio de Fomento, 2011). En ellos y en sus respectivos anexos, se aportan un conjunto amplio de datos censales de carácter socio-demográfico, y analíticos de carácter urbanístico provenientes tanto del análisis de los datos censales, como de los juicios facilitados por los responsables de las áreas de urbanismo de los ayuntamientos estudiados.

L2 ***Laguna de conocimiento 2****, Se necesitan modelos de evaluación alineados con planificación estratégica urbana:*
Tanto el apoyo institucional como el esfuerzo técnico brindado a este indicador **aún no se han materializado en una caracterización que incorpore por completo las últimas tendencias en el ámbito de la planificación estratégica**, ni que permita el desarrollo de herramientas de toma de decisión aplicables a la gestión urbana, pues para ello es necesario asumir la complejidad de la realidad más allá del análisis multi-criterio entre elementos de una misma escala, y extenderlo analizando las relaciones entre las diferentes escalas a fin de considerar también los efectos indirectos producidos por el entorno, y permitir enmarcar la decisión local dentro de una estrategia integral. Es necesario, como se avanza en el Informe General de 2001 a modo de propuesta de investigación futura, captar la evolución de los cambios de nivel de la vulnerabilidad urbana, interpretarla como respuesta a las tensiones favorables o contrarias que ha experimentado y buscar relaciones causales entre los sucesos que hayan podido provocarlas y su efecto sobre la vulnerabilidad urbana (Adger, 2006). Es necesario ir más allá de los juicios de expertos sobre la vulnerabilidad subjetiva de cada barrio, e integrar a los propios usuarios como interesados en el proceso de planificación recabando su percepción y preferencias (Munda, 2004). Es necesario, por último, aceptar tanto la incertidumbre sobre las condiciones futuras, como las limitaciones de los modelos predictivos y datos disponibles, construyendo modelos lo suficientemente robustos y dotados de capacidad estratégica como para poder adaptarse a circunstancias cambiantes sin perder su validez (Giezen et al, 2015; Lempert et al, 2006) y poder proveer a los decisores de soluciones efectivas y realistas (Yepes et al, 2015).

L3 ***Laguna de conocimiento 3****, Se requieren métodos que permitan identificar alternativas de actuaciones urbanas con un balance apropiado de riesgos y oportunidades:*
Esta necesidad de incorporar incertidumbres a la hora de seleccionar alternativas ha llevado al desarrollo de diversos sistemas de soporte decisional (DSS) con enfoques bottom-up (Hadka et al, 2015), que tienen por objetivo evaluar el comportamiento de las alternativas frente a un conjunto de escenarios determinados. A los efectos de estas técnicas, escenarios son cada uno de los hipotéticos estados futuros en los que puede llegar a encontrarse el

mundo (contexto) que rodea al modelo analizado, materializados en forma de combinación de valores tomados por las variables exógenas que afectan a dicho modelo (Lempert et al, 2006).

La mayor parte de estos sistemas se centran en el comportamiento de las alternativas en caso de producirse escenarios extremadamente negativos (Table 5.3), aunque también se han desarrollado modelos en los que esta evaluación, por el contrario, se realiza a partir de escenarios muy positivos. Los primeros apuntan a identificar un conjunto de escenarios frente a los cuales las alternativas son vulnerables (comportamiento peor de lo esperado), para determinar qué soluciones son más robustas, es decir, cuales presentan un mejor resultado frente a estos escenarios (Lempert, 2006). Los segundos, en cambio, identifican un determinado resultado positivo, que en el caso de algunos métodos como info-gap, no se trata de un resultado necesariamente factible sino ideal (Ben-Haim, 2006), y buscan soluciones desde las que resultaría relativamente más sencillo alcanzarlo. Sin embargo, hasta el momento **no han aparecido DSS** que identifiquen un conjunto de **escenarios relevantes**, **tanto vulnerables (negativos) como resilientes (positivos)**, para derivar, simultáneamente, los riesgos y oportunidades que estos representan para los planes de actuación en infraestructura (PAIs) urbana alternativos analizados. De esta manera, es posible evaluar las alternativas en términos de robustez y sensibilidad frente a posibles escenarios extremos (Black-Swans, Taleb, 2007) negativos y positivos.

L4 *Laguna de conocimiento 4*, *Es necesario considerar la incertidumbre relacional inherente a la implementación de planes de actuaciones urbanas en sistemas multi-escala:* La implementación de planes de infraestructura, en particular, se ve afectada por un tipo concreto de incertidumbre, derivada de la estructura más o menos descentralizada de las estructuras político-administrativas de los territorios en los que se desarrolla. Esta incertidumbre, denominada **incertidumbre relacional,** refleja los efectos que pueden derivarse de eventuales problemas de coordinación entre las diferentes escalas de un sistema. Dichos efectos son una carga para el sistema que debe ser minimizada, para lo cual **la comunidad científica sigue demandando métodos** de planificación que contribuyan a este propósito (Frank & Martínez-Vázquez, 2015) mediante la **evaluación de este tipo de incertidumbre** (Charbit & Gamper, 2015).

1.2. Objetivos de la investigación

A la vista de las lagunas de conocimiento expuestas en la sección anterior, cabe preguntarse si es posible resolver las carencias identificadas, esto es:

PI1 ¿Qué condiciones debe cumplir todo modelo de evaluación de vulnerabilidad urbana (MEVU) para que pueda integrarse con el resto de procesos de planificación estratégica urbana?.

PI2 ¿Qué modelo de evaluación cumpliría con las condiciones exigibles a todo MEVU?

PI3 ¿Cómo determinar el conjunto de escenarios deben considerarse, y que estrategias hay que resulten robustas frente a los riesgos y a la vez sensibles ante eventuales oportunidades?.

PI4 ¿Qué sistema de medidas político-administrativas resulta adecuado como acompañamiento de una determinada estrategia en su implementación a través de las diferentes escalas de un sistema de actuaciones urbanas?.

Esta tesis plantea abordar las cuestiones anteriores mediante un sistema de soporte decisional que permita seleccionar tanto un modelo de evaluación de la vulnerabilidad urbana, como planes de actuación con los que hacerla frente, en línea ambos con las últimas tendencias en planificación estratégica urbana. Además, la herramienta debe ser capaz de generar tanto alternativas de planificación como escenarios posibles y permitir al decisor la selección de un conjunto relevante de ellos para evaluar los riesgos y oportunidades de estos planes frente a los escenarios relevantes. Por último, el proceso decisional debe considerar la incertidumbre relacional asociada al sistema, y proponer medidas político-administrativas de acompañamiento.

La consecución del objetivo principal se sustenta en el cumplimiento de una serie de objetivos específicos:

- O1 Determinar qué requisitos deben cumplir los modelos de evaluación de vulnerabilidad urbana (MEVU).
- O2 Elaborar un sistema de soporte decisional que proponga modelos que satisfagan los requisitos identificados anteriormente, y permita seleccionar aquél que los decisores consideren más apropiado:
  - O2.1 Identificar interesados e incorporar sus preferencias si están disponibles. En su defecto, establecer las condiciones para obtenerlas.
  - O2.2 Captar la evolución del nivel de vulnerabilidad urbana de los distintos barrios>ciudades>CC.AA, y establecer una caracterización en base a la misma.
  - O2.3 Obtener una caracterización que permita establecer un ranking dentro de cada escala.
  - O2.4 Incorporar un enfoque cognitivo al proceso de manera que se obtengan criterios generales que puedan orientar la toma de decisiones.
  - O2.5 Incorporar un mecanismo que gobierne el proceso en su aproximación a los diferentes objetivos perseguidos, mediante el empleo de un modelo de

optimización multi-objetivo del que resulte posible extraer una información que, añadida a la proporcionada por el resultado del proceso, sea valiosa a la hora de interpretar el mismo. Esta información permitirá dirigir, dentro de un conjunto de soluciones óptimas, la selección de aquellas que resulten más convenientes.

O2.6 Implementar un sistema que permita acotar-sintetizar el conjunto de soluciones/MEVUs posibles en un conjunto manejable de estas, facilitando así la selección informada de un modelo de evaluación.

O3 Elaborar una herramienta que, partiendo de una propuesta de caracterización de vulnerabilidad urbana sea capaz de ofrecer alternativas de planificación que mejoren los niveles de vulnerabilidad urbana, y a la vez permita evaluarlas frente a un conjunto de escenarios relevantes de manera que puedan apreciarse por los decisores las diferentes implicaciones de cada una de ellas términos de riesgos y oportunidades, y seleccionar la más conveniente.

O3.1 Plantear planes de actuación en dichas infraestructuras que contribuyan a mejorar los niveles de vulnerabilidad urbana para los diferentes colectivos que se identifiquen.

O3.2 Generar escenarios posibles e identificar un conjunto de aquellos que resulten relevantes en función de las vulnerabilidades y resiliencias que comporten, para evaluar los niveles de riesgo y oportunidad de cada PAI alternativo respecto de los escenarios relevantes.

O3.3 Determinar un conjunto de medidas político-administrativas, en forma de contratos relacionales entre escala, que ofrezcan un adecuado acompañamiento de la alternativa de planificación seleccionada en su implementación a lo largo de la estructura político-administrativa del territorio considerado.

1.3. Metodología y estructura general de la investigación

Esta investigación se ha materializado en la elaboración de 4 artículos, recogidos en sendos capítulos, que responden a una secuencia metodológica con la que alcanzar los objetivos previstos, y definen la estructura de esta tesis. De estos cuatro artículos, tres han sido publicados y otro más se encuentra en proceso de revisión (Figura 1.1).

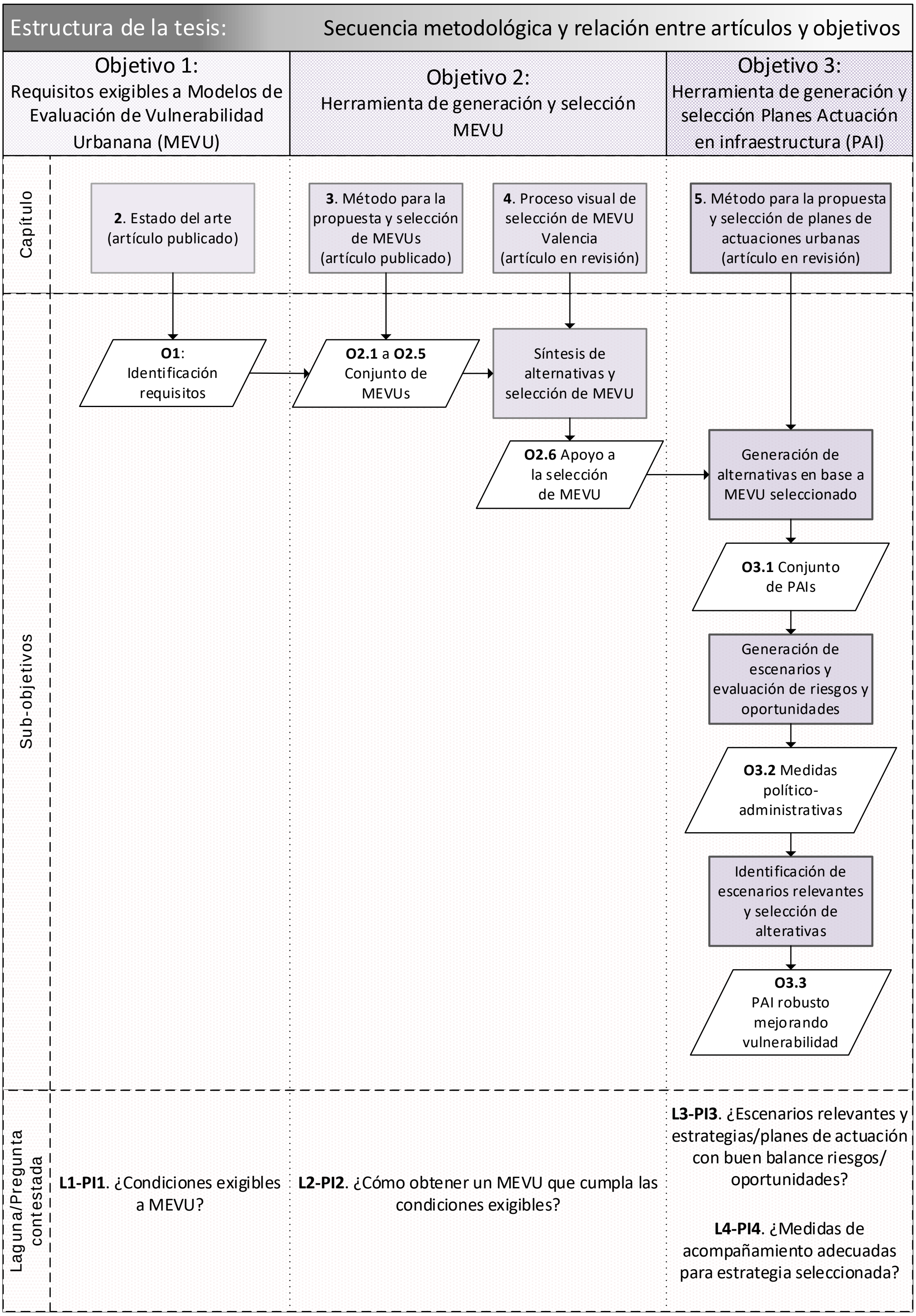

Figura 1.1 Estructura de la tesis

Capítulo 2, Tendencias actuales en materia de Evaluación de Vulnerabilidad Urbana/ Current trends in Urban Vulnerability Assessment :

Tras el Capítulo 1, de introducción, el Capítulo 2 presenta el artículo ***Urban vulnerability assessment: Advances from the strategic planning Outlook***, sobre el estado del arte, en el que se traza un paralelismo entre la evolución y últimas tendencias en los campos de planificación estratégica urbana y de evaluación de la vulnerabilidad urbana. A partir de esta revisión, que determina las características de ambas tendencias, se evalúa en qué medida estas convergen entre sí. De este análisis, se desprende qué requisitos deben exigirse a los modelos de evaluación de vulnerabilidad urbana (MEVU) para considerarlos alineados con las últimas tendencias en planificación estratégica.

El estudio realizado revisa métodos de evaluación de vulnerabilidad urbana de 2010 en adelante presentes tanto en la Web of Science como en Scopus, y cuantifica cuantos de los requisitos exigibles están presentes en cada método. En una segunda etapa, el resultado de este análisis es evaluado tanto cualitativa como cuantitativamente para determinar la tendencia que presentan los métodos de evaluación desarrollados en los últimos años.

Este capítulo se relaciona con la laguna de conocimiento L1, la preguntas de investigación PI1, y con el objetivo O1 (Figura 1.1).

Capítulo 3, Metodología para la selección de Modelos de Evaluación de Vulnerabilidad Urbana/ A method for selecting Urban Vulnerability Assessment Models:

El Capítulo 3 introduce otro artículo, ***A discursive, many-objective approach for selecting more-evolved urban vulnerability assessment models***, en el que se presenta una metodología que permite seleccionar MEVU acorde con los requisitos identificados anteriormente, y se describen en detalle los fundamentos teóricos de dicha propuesta. La metodología propuesta aborda la integración de estos requisitos a través de un proceso discursivo en el que las interacciones entre los decisores y el método permiten avanzar hacia la obtención del MEVU que presente la combinación más adecuada de niveles de satisfacción de los diferentes objetivos perseguidos. Estos objetivos son:

- el grado de alineamiento de los indicadores incluidos en cada MEVU con aquellos preferidos por los expertos consultados.
- la bondad del ajuste estadístico de dicho MEVU, la robustez frente a errores en la información cuantitativa empleada.
- la conexión dinámica temporal a lo largo de los dos períodos considerados, a saber, 1991 a 2001 y 2001 a 2011.
- La similitud entre indicadores elegidos para cada una de las diferentes escalas político-administrativas que se evalúan: barrio, ciudad, provincia, región y país.

El marco de evaluación de vulnerabilidad urbana propuesto facilita, para las entidades de un área en sus diferentes escalas, tanto su estado de vulnerabilidad, como el riesgo de incrementarla en el futuro, permitiendo así el empleo de este concepto como criterio a la hora de planificar la asignación de recursos, destinados a reducir la vulnerabilidad urbana, entre las diferentes entidades candidatas.

Este marco hace uso de información cualitativa, recabada mediante el empleo de la técnica multicriterio Analytic Hierarchy Process (AHP) para recoger las preferencias de los usuarios potenciales con respecto a los indicadores que consideran más relevantes, como de la información cuantitativa disponible en el Observatorio de Vulnerabilidad Urbana. A partir de esta información, y en base a la clasificación básica de entidad vulnerable/no vulnerable manejada por el Minsterio de Fomento, se determinan tanto el Estado de Vulnerabilidad como el Riesgo a incrementarla. El primero se obtiene mediante el análisis de componentes principales de las variables propuestas para caracterizar la vulnerabilidad urbana. Dicha técnica permite construir rankings del Estado de Vulnerabilidad de cada entidad al inicio y final del período considerado, cuya evolución establece las clases utilizadas para determinar, mediante el empleo del análisis discriminante, la probabilidad de incrementar, mantener o reducir el nivel de vulnerabilidad urbana. Dicha probabilidad, junto con el impacto que tendría un eventual cambio de nivel, determinado mediante una regresión lineal, dan como resultado el Riesgo que presenta cada entidad al final de cada período.

El proceso de generación y selección de alternativas se articula mediante los módulos de optimización mulit-objetivo y control. Mientras que la optimización produce soluciones de compromiso, el módulo de control supervisa el proceso, proporciona un control dinámico y permite las interacciones. Estas interacciones consisten en las decisiones intermedias que debe tomar el equipo decisor, y se informan con el conocimiento derivado del enfoque cognitivo implícito en el método, que permite una mejor comprensión de la dinámica del proceso.

Finalmente, el artículo presenta, como caso de estudio, la aplicación de esta metodología al territorio español en base a datos procedentes del Instituto Nacional de Estadística y al Observatorio de Vulnerabilidad Urbana.

En este artículo, se intenta cubrir la laguna de conocimiento L2 dando respuesta a la pregunta de investigación PI2, y se intentan alcanzar los objetivos O2.1 a O2.5 (Figura 1.1).

Capítulo 4, Proceso de selección de un Modelo de Evaluación de Vulnerabilidad Urbana/ Process of selecting an Urban Vulnerability Assessment Model:

El Capítulo 4 recoge el artículo ***VisualUVAM: a decision tool addressing the curse of dimensionality for the selection of urban vulnerability assessment models***, actualmente en revisión, en el que se introduce la herramienta decisional VisualUVAM y se describen de forma pormenorizada las diferentes interacciones entre el decisor y la parte lógica del modelo, que son necesarias para completar el proceso, a través de su aplicación a los municipios de la provincia de Valencia. VisualUVAM es un sistema decisional que partiendo de la metodología propuesta en el Capítulo 3, provee al decisor de un marco de herramientas de análisis visual, interacción y análisis cluster que facilita la interacción entre el decisor y el dispositivo lógico, y permite sintetizar el universo de alternativas en un conjunto manejable de soluciones representativas. De este modo, se reduce la carga decisional añadida que supone tener que elegir entre un número excesivo de alternativas, facilitando de este modo la labor del equipo decisor.

La herramienta decisional presentada se apoya en el uso de métodos de análisis visual para facilitar, por un lado, la inferencia de las relaciones entre objetivos. Así mismo, estas técnicas permiten tanto explorar los resultados de diferentes entidades evaluadas por un mismo MEVU (visualización bottom-up), como analizar un conjunto de MEVUs bajo la óptica de los resultados que producen para una entidad determinada (visualización top-down).

El método de selección de alternativas propuesto facilita la delimitación, mediante controles interactivos, de un conjunto relevante de estas, que puede a su vez ser sintetizado a través del análisis de conglomerados. La fórmula empleada se basa en el método k-means, y agrupa el conjunto de alternativas en un número k de particiones, de cada una de las cuales se obtiene un MEVU representativo elegido como aquel que resulte mejor, de entre todas las alternativas de cada cluster, para el objetivo deseado.

Así mismo, este artículo propone una herramienta interactiva mediante la cual es posible, siguiendo el método AHP, recoger las preferencias de expertos por el empleo de unos u otros indicadores, de manera que se garantice la consistencia de dichos juicios, evitando así tener que recurrir a segundas vueltas o manupulación de juicios en el supuesto, bastante habitual, de detectar inconsistencia en los juicios recopilados durante el procesado de los mismos.

El artículo presentado en este capítulo contribulle a solucionar la laguna de conocimiento L2, relacionada con la pregunta de investigación PI2, y se centra en la consecución del objetivo O2.6, reforzando a la vez la consecución de los objetivos O2.1 a O2.5 (Figura 1.1).

Capítulo 5, Evaluación de riesgos y oportunidades derivados de incertidumbres relacionales asociadas a la planificación de infraestructuras/ Evaluation of risks and opportunities arising from relational uncertainties associated with infrastructure planning:

El Capítulo 5 presenta el artículo ***MS-ReRO and D-ROSE methods: assessing relational uncertainty and evaluating scenarios' risks and opportunities on multi-scale infrastructure systems***, ya publicado, en el que se propone un nuevo sistema de soporte decisional. A partir del modelo de evaluación de vulnerabilidad urbana obtenido en el capítulo anterior, este nuevo sistema plantea alternativas de planificación urbana que resultan óptimas para una serie de objetivos. Estos objetivos se han diseñado de manera que representen a los diferentes grupos de interés que se han considerado, y permitan sopesar alternativas en función de los niveles de satisfacción que ofrecen para cada grupo en cuanto a impacto sobre su vulnerabilidad urbana, y sobre su coste económico. Para la confección de este modelo, se han empleado datos procedentes de la Encuesta de Infraestructura y Equipamientos Locales (EIEL), y de otros organismos oficiales.

El modelo relaciona, a través de un modelo de regresión lineal obtenido mediante el proceso step-wise, la evolución de la vulnerabilidad urbana que ofrece el MEVU seleccionado en el Capítulo 4, con la evolución del equipamiento en infraestructuras en cada una de las entidades analizadas. A continuación se relacionan estos cambios en los niveles de equipamiento, con las actuaciones que las habrían producido, de manera que siguiendo el camino inverso pueda derivarse el efecto que tendrían un conjunto de actuaciones sobre los niveles de vulnerabilidad urbana. Así, el problema de optimización multi-objetivo planteado puede construir planes de actuación hipotéticos, y localizar aquellos que ofrecen combinaciones óptimas para los objetivos considerados, que incluyen mejorar la eficiencia económica, y los los niveles de vulnerabilidad urbana tanto del sistema en su conjunto como de los diferentes grupos de interés.

Adicionalmente, este artículo presenta dos nuevos métodos para incorporar incertidumbre al proceso decisional. D-ROSE genera escenarios posibles, permite identificar un conjunto de escenarios relevantes y evalúa las alternativas en términos de los riesgos y oportunidades que ofrecen frente a este conjunto de escenarios. MS-ReRO, por su parte, analiza la incertidumbre relacional exclusivamente y permite proponer, en base a este análisis, medidas politico-administrativas de acompañamiento en forma de sistemas relacionales jerárquicos en los que se transfieren competencias desde las escalas superiores a las inferiores.

Para ello, D-ROSE hace uso de la Simulación Montecarlo a la hora de generar escenarios, y siguiendo la nueva metodología propuesta, para identificar el conjunto de escenarios relevantes tanto positivos como negativos y calcular, en base a este conjunto, los riesgos y oportunidades asociados a cada alternativa de planificación.

A diferencia del caso anterior, MS-ReRO utiliza el método de Simulación Montecarlo, para calcular las probabilidades posteriores de cada entidad de empeorar o mejorar el resultado esperado en el caso de empeoramiento o mejora de las sub-entidades que la componen. Partiendo de estas probabilidades y aplicando la ley de la probabilidad total, MS-ReRO determina la probabilidad total de fallo del sistema como consecuencia del fallo de sub-sistemas. El impacto, que se obtiene en términos de la desviación presupuestaria que tendrían dichos fallos, es multiplicado por la probabilidad para obtener el riesgo inherente a cada sistema relacional.

De esta manera, el artículo presentado en este capítulo cierra las lagunas de conocimiento L3 y L4, relativas a los riesgos y oportunidades asociados a la incertidumbre relacional inherente a los sistemas de infraestructura multi-escala. A la vez, plantea respuestas a las preguntas de investigación PI3 y PI4, y persige el objetivo O3 (Figura 1.1).

El **Capítulo 6** es una **discusión** de las aportaciones recogidas en cada uno de los artículos sobre la que finalmente, en el **Capítulo 7**, se extraen **conclusiones** a esta investigación y se señalan limitaciones a la misma.

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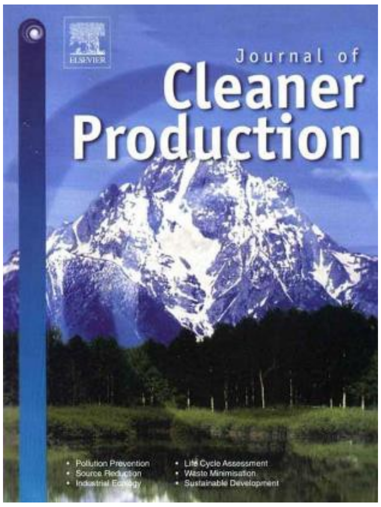
Capítulo 2

Current trends in Urban Vulnerability Assessment-Tendencias actuales en materia de Evaluación de Vulnerabilidad Urbana

Artículo 1: Urban vulnerability assessment: Advances from the strategic planning outlook

Publicación



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Abstract

Urban strategic planning and urban vulnerability assessment have increasingly become important issues in both policy agenda and academia. However, a comprehensive review of the advances made in urban vulnerability, emphasizing their shared aspects, has yet to be performed. The aiming of this paper is to addresses the latter by conducting an evaluation on assessment methods disclosed in this decade. Once their common evolutive pathway is traced, the review follows an analytical framework, based on the above, evaluating the research requirements from both a quantitative and qualitative point of view. Our findings indicate that the robustness, cognitive and participatory research lines are those in which most advancement has been made, while those of urban dynamics and multi-scale progressed the least. Our analysis also demonstrates that methods integrating more lines of research, as well as the employment of comprehensive approaches, promotes advancing the developmental stage. We conclude that the focusing of research lines should be shifted, in order to bridge the qualitative gap identified without demanding an improbable, quantitative increase.

Keywords: urban vulnerability, urban strategic planning, vulnerability assessment, current trend.

2.1 Introduction

Urban vulnerability (UV) in general, and its adaptive component in particular, have become key issue for urban strategic planning (USP) (Rigillo & Cervelli, 2014; Nahiduzzaman et al., 2015), and for coping with climate change (McCarthy, 2001; Turner et al., 2003; Adger, 2006; Füssel, 2007; Birkmann et al., 2014; Chang & Huang, 2015). Therefore, vulnerability assessments are increasingly being used by governments around the world (Fekete, 2009) for the purpose of strategic planning. This latter can be defined broadly as an effort to develop fundamental decisions and actions that shape and guide what an organization is, what it does and why it does it (Bryson et al., 2004). On the other hand, USP is a way of urban planning that is based on strategic planning, which foundations have evolved from the Control and Optimization paradigm, to the Discursive approach (Malekpour et al., 2015).

Regarding vulnerability, its most accepted definition (to climate change) is provided by the IPCC Assessment Report (McCarthy, K.S., & (eds), 2001) as follows: “The degree to which a system (entity) is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity”. Nevertheless, there are many other definitions that challenge current thinking, to the extent that it is necessary to perform research specifically aimed at conceptual clarification (Füssel & Klein, 2006; Wolf et al., 2013), which exceeds the scope of this study. A few aspects, however, are beyond question, one being the research requirements set in studies related to the assessment of this concept. Since urban vulnerability is a particularization of the general vulnerability concept, the entity being an urban framework, they share the aforementioned research lines (Romero Lankao & Qin, 2011), which are close to those of USP. Thus by determining which attributes makes USP, which has a relatively long history, effective and then comparing that to recent Urban Vulnerability assessments (UVA) methods, it can be determined which of these requirements are missing in UVAs, and consequently appraise the advancement made on this field.

Accordingly, the questions that necessarily arise are what attributes characterize current USP research, and to what extent are them being followed by UVA research. Likewise, it is important to ascertain whether we can improve the existing progression, and if so, how. To respond these questions, a detailed review of the UVA area in the light of a comparative between USP and UVA evolutions, is needed. Thus, the scope of this work is shaped by urban vulnerability assessment methods disclosed from 2010 onwards, whose entity (system) is an urban framework. For the gathering of these methods, we employed a four-step process in which, by means of a general search, a forward search, a brief review and a content analysis, we systematically proceeded from studies regarding urban vulnerability in general to those presenting new UVA methods. By following those steps, this paper traces the evolutionary pathway, common for USP and UVA (Section 2) to develop, on this basis, an analytical framework (Section 3), which is applied to a sample of UVA methods (Section 4) in order to establish current advances and trends. The results reveal (Section 5) current research preferences, relations with other aspects such as schools of thought, stimuli or developmental stage, and inner synergies, all of which will allow for a desirable, plausible future to be envisaged, and insights for its achievement (Section 6). The paper concludes (Section 7) that the infrastructure-related stimuli are the most promising, and that a shift in focus towards the integration of cognitive, multi-objective, multiscale and dynamic research requirements would benefit the advance of urban vulnerability research.

2.2 Evolution

There has been a major evolution in the development of both USP and vulnerability assessment methods, which enable a common underlying pattern to be inferred. This similarity is made evident by introducing and comparing USP and UVA evolutions and research lines.

2.2.1 Strategic planning

On the one hand, as far as USP is concerned, its importance and goals have evolved from simple prediction models playing a minor role in post-WWII economic stabilization, to a protagonist one as a potential tool to assist the decision-making processes undertaken by today's urban planners. This process takes place by fostering the incorporation of those existing uncertainties and complexities in reality, changing from formulaic processes to discursive practices, and by the involvement of key stakeholders. The stages, in which the main objective was to maximize the available resources, or minimize the negative impact of the decisions, have given way to a new one recognizing the effect of uncertainty upon results, its unpredictability and the necessity of providing solutions that may help to meet changing circumstances (Malekpour et al., 2015).

Broadly speaking, three stages can be identified in this evolution: the first in which strategic planning served to make predictions and take decisions accordingly (predict-and-act). The second, in which not only were predictions made but also several possible future scenarios were contemplated, and further criteria on managing available resources were established. The third stage, in which it is accepted that any predicted future will change and only broad directions of this change, as well as criteria to adapt to the coming circumstances, can be given. Malekpour et al. (2015) have called these three stages incremental, managerial and discursive; and incremental, modeling- managerial and discursive by Dominguez et al. (2011).

2.2.2 Vulnerability assessment

On the other hand, as far as vulnerability is concerned, its conceptual framework and lines of future research have evolved in a similar way: from the initial prediction, based on simplified models assessing impacts, to the current conceptualization. In the latter not only the impacts, but also the entity's capacity to improve its ability to anticipate hazards, to address them, and to overcome their consequences, are taken into account (Kaźmierczak & Cavan, 2011). All this is accomplished by incorporating the uncertainty and complexity inherent in the real world (Munda, 2004; Füssel & Klein, 2006) and by taking into account both the dynamic nature and the subjective side of vulnerability (Adger, 2006; Liu et al., 2010; King & Blackmore, 2013; Pamungkas et al., 2014; Birkmann, et al., 2014). The initial and the current developmental stages have been referred to, respectively, as the preparation and the adaptation stages by Adger (2006), and as the impact assessment and the adaptation policy by Füssel et al. (2006). Between them, an intermediate development stage was also identified, in which not only was an impact assessment provided, but also an evaluation of the entity's adaptability. These developmental stages are put into a correlation in Table 2.1, which portrays how the methods have evolved. Regarding the time horizon considered, they changed from exclusively considering long-term planning (Füssel, 2003), to the establishment of the mid-to-long-term potential consequences of climate variability (National Assessment Synthesis Team, 2001), and on to providing assessments in the long and short term by allowing evaluations at different time slices (Harrison et al., 2015). Likewise, these examples illustrate how the consideration of adaptation has changed. In the first example, the assessment relies only on biophysical indicators without taking into account other aspects, such as socio-economic or socio-political aspects, related with the communities' adaptive capacity, which in contrast are taken into account in the other examples, and can lead to adaptive strategies. As to the incorporation of uncertainty, its treatment has ranged from its partial consideration, in the first case, by applying climate projections from different general circulation models, to a more extensive incorporation by investigating, in the other two cases, its effect on climate models by comparing the outcomes produced by different scenarios. These latter, in the case of the studies pertaining to the vulnerability and adaptation stages, were identified with the help of the involvement of the stakeholders, in contrast with the impact tool, which made no use of any kind of participatory process. In line with the evolution of stakeholder involvement, the analytical approaches employed have varied from the normative approach used in the adaptation stage example, in which the stakeholders themselves build the scenarios determining the models' outcomes, to the positive, found in studies representing the vulnerability and impact stages.

In these latter, the role of stakeholders was only to help the scientists understand their needs, which drove a more linear and less policy-driven assessment. As to the understanding of the complex nature of vulnerability, the examples provided portray how they have changed from a biophysical model (reducing it to a single dimension), to a comprehensive one enabling a better understanding of complex cross-sectoral and multi-scale interactions.

	Domain:		Stages:			Reference:
Developmental stages	Urban strategic planning		Incremental	Managerial	Discursive	Malepour et al., 2015
			incremental	Modeling-managerial	discursive	Dominguez et al., 2011
	Vulnerability assessment		impact assessment (Fussel, 2003)	vulnerability assessment (National Assessment Synthesis Team, 2001)	adaptation policy (Harrison, 2015)	Fussell et al., 2006
			preparation	adaptation		Adger, 2006
Characteristic evolution	Urban strategic planning / vulnerability assessment	Time horizon	long range planning / long-term	strategic (present and long range) planning/ mid- to long-term	strategic (present and long range) planning / short-to long-term	Malepour et al., 2015 / Fussell et al., 2006
		Consideration of adaptation	control status quo / little	optimization of status quo / partial-full	adaptive planning / full	
		Consideration of uncertainty	future forecast / little	uncertainty management through scenario planning / partial	umpredictability is accepted, uncertainty is explored / extensive	
		Stakeholder involvement	public sector /low	public-private, stakeholders invonvement / medium	citizens' involvement / high	
		Analytical approach	rational / positive	cognitive / mainly positive	Cognitive and post-normal / normative	
		Integration-complexity asumption	from linear to non-linear complex patterns / low	complexity theory, predict-and-act / medium-high	adaptive approaches / high	

Table 2.1 Developmental stages and their characteristic evolution

2.2.3 Common research lines

These similarities between USP and UVA can also be found in their current challenges and consequent research directions (Table 2.2).

Table 2.

	Current requirements		Current challenges
domain:	urban strategic planning	urban vulnerability assessment	common
requirements:	robustness	robustness	deal with uncertainty
	multi-objective capacity	risks and opportunities management	manage multiple alternatives
	multi-scale	multi-scale	incorporate complexity
	participatory process	sensitive to subjective vulnerability	promote public involvement/subjectivity
	urban dynamics	urban vulnerability dynamics	capture dynamic nature
	cognitive approach	causal relationships identification	discursive/adaptation policy approaches

Table 2.2 Research requirements of USP and UVA.

According to several authors, for the present, dealing with uncertainty is a major challenge for USP (de Graaf & Dewulf, 2010; Malekpour et al., 2015); In addition, dealing with conflict, multiple valuation criteria or multiple alternatives as well as citizen involvement in the planning process are challenges for strategic urban planning, and have become major concerns. For the accomplishment of each purpose, several requirements are needed. Therefore, increasing the assessment robustness was pointed out as a proper method for facing uncertainty (Malekpour et al., 2015). Strategic capacity also referred to as strategic ambiguity, can deal, through the use of (for example) multi-objective optimization (MOO) approaches, with conflicts and multiple objectives (Giezen et al., 2015). This is achieved by means of MOO compromise solutions, which are able, unlike multi-criteria analysis, to deal with multiple dimensions, even when they are in conflict with each other (Munda, 2004). The incorporation of the social point of view and its preferences, subjective as they are, is what ultimately could be provided by the required social learning and participatory process (Malekpour et al., 2015; 2016; Zamarrón-Mieza et al., 2017).

Cognitive approaches have become relevant for the purpose of providing insights and to ease the extraction of relevant information, and should be present in USP, since it must be designed as a learning process, aiming to build a consensus in which different actors are considered (Wiechmann, 2008). On the other hand, the current USP trend focuses on the planning process itself rather than only on its results, and a cognitive approach empowers this feature (Yepes et al., 2015; Torres-Machi et al., 2017). Thus, cognitive approaches ease planners and decision-makers to grasp the underlying cause-effect relations, which are a requirement for UVA (Adger, 2006). Furthermore, facing multiple objectives makes explicit the trade-offs between them, contributing to their balance and thus reinforcing the value added by discursive strategies.

From the urban vulnerability point of view, current research directions have also been highlighted, and several requirements were outlined, such as the improvement of the assessment models' robustness, recognizing and managing risks (Nahiduzzaman et al., 2015) and opportunities, identifying causal relationships, developing models sensitive to subjective vulnerability, inclusion of participatory processes in which vulnerable sections are taken into account, as well as the incorporation of the complexity and multi-scale nature of vulnerability into the characterization methods (Adger, 2006). Along with capturing UVA's subjective side, which consists of a experiencing of stimuli due to subjective, non-material considerations, also grasping the dynamic character of vulnerability has been marked out as a challenge for vulnerability research (Adger, 2006). Table 2 summarizes the set of requirements of both USP and UVA lying the foundations of the analytical framework used to review the identified assessment methods (section 3.2), and makes explicit their interconnection as responses for the identified common challenges

2.3 Conceptual framework for UVA

This section introduces the conceptual framework used to assess to what degree advances on the above research objectives have been made. This scheme focuses on four different aspects of the assessment methods, namely their approach, stimuli, development stage and addressed requirements of research directions. While the first three aspects relate to the generic attributes of evaluation methods allowing a qualitative analysis, the latter has to do with the quantitative aspect of the research effort made, and serves as the basis for the analytical framework whence the advancement made on the research required has been assessed.

2.3.1 Generic attributes

2.3.1.1 Approach

Upon the basis of the works carried out by Brooks (2003) and Füssel and Klein (2006), the UVA methods are classified according to the following typologies:

a) Biophysical approaches, in which the vulnerability concept arises from non-human factors.

b) Social approaches, relating to human behavior and societal characteristics.

c) Comprehensive approaches, in which both biophysical and social factors are taken into account for the vulnerability characterization.

2.3.1.2 Stimuli

Stimuli refer to the type of perturbation acting upon the entity. A wide range of stimuli can be considered (Wolf et al., 2013). Therefore, a brief review of the selected studies was carried out, resulting in the following groups of hazards: seismic, water flooding, generic natural, underground infrastructure operational failure, surface infrastructure operational failure, and social affairs. So far as these stimuli are susceptible of having been produced by others or not, these have in turn been respectively classified as 2nd or 1st Order stimuli.

2.3.1.3 Developmental stage

Developmental stage: The classification of developmental stages, including the impact, vulnerability, and adaptation assessment categories, was determined according to Füssel et al., (2006) (Table 2).

2.3.2 Research attributes

The final, core stage of the analysis looked at the research requirements addressed in the evaluated methods. The common requirements for both USP and UVA, which in Table 2 are related to the developmental stages, are:

2.3.2.1 To be robust, as a way to cope with uncertainty.

Robustness can be understood as the ability of a model to withstand variations in the inputs without experiencing significant changes in its output.

As an instance of robustness assessment, consider two possible indicator-based assessment models ranking a set of areas by their environmental vulnerability (Andres et al., 2017), in which the indicators are affected by uncertainty, represented as probability distributions. If we run each assessment model many times, as in a Monte Carlo simulation (Penades-Pla et al., 2016), changing each time the values of the indicators according to the given distributions, we obtain a new ranking each time we run the model. For each model thus evaluated, its robustness would be assessed as the inverse of the variance attached to the set of new rankings obtained, i.e., the more robust model will be that in which the rankings varied the least.

2.3.2.2 To have the ability to incorporate participatory processes and to take into account subjectivity.

The engagement of stakeholders has become usual in USP. However, citizen involvement in the planning process is still a challenge for both USP and UVA; it can be handled by means of the implementation of participatory processes (McCormick, 2016) such as those already present in environmental assessment (O'Faircheallaigh, 2010). Public participation involves the transmission of information to decision makers by the public, and may help the smooth implementation of projects or programs. Moreover, through social learning, these participatory processes can provide the social point of view and the preferences needed for grasping the subjective character of vulnerability (Malekpour et al., 2015), as has been requested for UVA assessment methods. This subjective side refers to how people's experience of the same event differs (Adger, 2006) and it is, therefore, a relative, context-dependent concept (Cutter et al., 2003).

2.3.2.3 To take into account complexity and the multiplicity of scales.

Since vulnerability is context-dependent and of a complex nature (Adger, 2006), taking this into account requires dealing with complexity. Besides, the relations between any urban element and its context are, in the case of urban fabrics, somehow hierarchical, for example, neighbourhoods are contextualized by cities, which in turn are contextualized by provinces, and so on. This socio-political, multi-scale character of UVA is somewhat similar to the well-known layering of an environmental assessment (EA), represented as a linear cascade of rules and action which starts with an assessment at the policy level, descends to the levels of plans and programs, and ultimately ends with an EA at the project level (Slootweg & Jones, 2011). Therefore, comprehensive approaches shall consider the relations of each element not only within its own scale, but crossing the multiple layers composing urban vulnerability. In a similar vein, the adoption of holistic approaches is recommended to perform accurate environmental assessments of complex systems, such as territories, providing an integrated assessment of entities in a territory from local to overall scales

(Loiseau et al., 2012). Such approaches to dealing with complexity are already embodied in cascade-failure methods, tracing, for a system, the chain of events leading to the production of effects as a consequence of the partial or total failure of one or more of its sub-systems.

2.3.2.4 To have the capacity to capture the dynamic nature of urban vulnerability.

Since vulnerability is context-dependent, and this context changes, methods intended to take into account the dynamic nature of UV should consider it rather as an evolution than as a static state, unconnected with others, corresponding to a given situation. Therefore, those aspects in terms of which the context changes, such as time or political-administrative scale, are significant criteria in terms of which to define vulnerability, as well as to understand the underlying dynamics of any environmental system (Slootweg & Jones 2011). For this reason, UVA assessments should provide not only the current vulnerability state, but also the risk of becoming more vulnerable over time (Adger, 2006; Birkmann et al., 2014). On the other hand, just as the characterization of EA dynamics demands taking into account the interactions between the scale being analyzed and those scales above and below it (Slootweg & Jones, 2011), so UVA methods need to relate entities of one scale with the corresponding entities in the scales above and below.

2.3.2.5 To manage multiple objectives.

Since stakeholder involvement in planning provides different interests to take into account, which can eventually be in dispute, methods allowing for simultaneously analysing the issue at stake from the perspectives of the multiple interests affected are demanded. This feature cannot but contribute to enhance the capacity of overcoming conflicts of interest that may arise during the planning process, allowing the adoption of strategies partly satisfying several, eventually conflicting requirements, instead of fully satisfying one given objective alone, as in the case of a mono-objective approach. Take, for example, the case where a town's inhabitants must determine the amount of allowable pollution that can be emitted by a factory into a nearby lake over a given planning horizon (Hadka et al., 2015). By means of a multi-objective approach, the inhabitants will be enabled to take their decision after having observed the problem from the points of view of minimizing phosphorus in the lake, maximizing economic benefit, maximizing inertia, and maximizing reliability. Besides, they will have a set of compromise solutions at their disposal from which to choose.

2.3.2.6 To make use of cognitive approaches

Some assessment techniques provide information concerning the trade-offs between the criteria framing the UV concept assessed, therefore enhancing the identification of cause–effect relations. This information may be transformed, by means of its analysis within the assessment method, into knowledge valuable for the process. In consequence, techniques such as multi-objective optimization, when implemented in methods such as discursive approaches, allow the exploitation of the information generated, affording knowledge which can be dynamically used to improve the model, or guide its development. Following the example of the point above, the multi-objective approach employed for the environmental assessment of the situation with the lake lets the inhabitants draw conclusions regarding the relations between the objectives, which enabled them to learn the dependencies between their decisions and the system’s performance, and discover the cost–benefit compromises offered by various strategies.

2.4 Methodology: selection of studies

Once an analytical framework for the review of UVA methods was established, a literature review was carried out to elucidate the advancement of urban vulnerability models. A four-step process was used for this purpose. In the first step, a comprehensive search was conducted under the Title/Keyword/Abstract (T/K/A), data range and subject area fields of the search engines Scopus and Web of Science. Urban vulnerability was the term used in the T/K/A search field. Since our aiming was to find out the current trend on UVA research, we focused our revision in methods developed in the last years. The cutoff year of the search was determined upon the basis of the latest study found reviewing urban vulnerability research (Romero Lankao & Qin, 2011). This latter, although focused on the conceptualization rather than on the assessment of UV, summarized previous research, and identified several research directions. In addition, being the aim of this work the role that urban vulnerability plays into strategic urban planning, only "social sciences" and "engineering" were selected as subject areas for the search. In the second step, a forward search carried out, by means of which more works developing new UVA methods were identified. 24.29% of the articles reviewed were unreferred in further works, while 49.22% and 26.49 were cited between 1 and 5 times, and six or more, respectively. Only 7% of all the UVAs analyzed were cited in new methods henceforward developed, which might be understood as a low performance as inspiration source. In the third step, a brief review of the resulting studies was performed, selecting those whose relationship with urban vulnerability was asserted through evaluating the title's meaning. Finally, as fourth step, a content analysis of the selected papers was followed to identify those studies including UVAs, resulting in 65 publications. An evaluation was then conducted to ascertain to what degree the advances had been achieved as far as the current urban vulnerability research objectives were concerned.

2.5 Results, descriptive analysis of the research effort made

This section examines the selected urban vulnerability assessment methods upon the basis of the above conceptual framework *(*section 3.2), highlighting the main findings regarding with the evolution of UVA methods. Therefore, results shaping and contextualizing the state of UVA were presented, and a discussion tackling the research effort made for the UVA methods in general was ensued. For the analysis of the resulting data, the statistical software Minitab 17 was employed.

2.5.1 Contextualization of UVA

Table 2.3 Description of urban vulnerability assessment methods.shows that biophysical, comprehensive and social approaches had nearly the same proportion. A current trend was inferred for the biophysical and comprehensive schools of thought, whose higher means depicted their increasing growth.

Mean and Std refers to the distribution of Studies according to their Attributes, along columns.

Reference values for means are provided at the bottom

Atributes	Studies		Year (*)		Approach (**)		Evol. stage (***)		Simultaneous req.	
	Count	%	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
approach:										
(1) biophysical	22	34	41,620	476			1.833	0.541	0.777	1.000
(2) comprehensi	23	35	41,799	621			2.13	0.548	0.826	0.936
(3) social	20	31	41,55	581			1.778	0.427	0.667	0.618
Evol. stage:										
impact	10	15							0.7	0.675
vulnerability	48	74							0.651	0.814
adaptation	7	11							1.667	1.003
Stimuli:										
1st Order:										
natural	12	12	41,77	678	2.182	0.751				
seismic	18	34	41,52	511	1.875	0.885				
water	20	24	41,78	640	2	0.686				
social	9	18	41,59	362	2	0.756				
2nd Order:										
underg.	3	6	41,51	843	2.333	1.155				
surf. Infras	3	6	41,76	210	1.677	1.155				
Simultaneous req..:										
0	30	47					1.893	0.416		
1	22	34					1.8	0.523		
2	9	14					2.25	0.707		
3	3	5					2.333	0.577		

Note: Reference values closer to aspect means indicates the category to which the latter is more prone:

(*) reference values corresponding to each year: 2010=40,361; 2011=40,762; 2012=41,091; 2013=41,457; 2014=41,882; 2015=42,187;

(**) reference values corresponding to each approach: biophysical= 1; comprehensive = 2; social=3

(***) reference values corresponding to each evol. stage: impact=1; vulnerability=2; adaptation=3.

(1) Biophysical references: Zhang et al., (2010); Chiauzzi et al., (2011); Albuquerque et al., (2013); Bristow, E. C., & Brumbelow, K. (2013); Aina, Y. A., & Aleem, K. F. (2014); Duggal, B. (2014); Kaji et al., (2014); Moradi et a., (2014); Novelli et al., (2014); Radmehr, A., & Araghinejad, S. (2014); Shieh et al., (2014); Ouma, Y., & Tateishi, R. (2014); Yuan et al., (2014); Christodoulou, S. E., & Fragiadakis, M. (2015); Deng et al., (2015); Guardiola-Víllora et al., (2015); Kirshen et al., (2015);Mokhberi, M. (2015); Saha, M., & Eckelman, M. J. (2014); Sun et al., (2015); Fischer et al., (2016); Rosenzweiget al., (2011);

(2) Comprehensive references: Bendaoui et al., (2010); An et al., (2011); Cagno et ,al., (2011); Sabato, V., & Mugavero, R. (2012); Solín, L. (2012); Ferreira et al.., (2013); Bosiljkov et al.., (2014); Cai et al., (2014); Heaton et al., (2014); Kimani-Murage et al., (2014); Remki, M., & Benouar, D. (2014); Shuang et al., (2014); Syed et al., (2014); Giardina et al., (2015); Radmehr, A., & Araghinejad, S. (2015); Shach-Pinsly, D., & Ganor, T. (2015); Su et al., (2015); Ding et al., (2016); Shenet al., (2016); Codjoe & Afuduo, (2015); Mohammad & Zahmatkesh, (2017); Kriščiukaitiene et al., (2015); Armaş et al.,. (2016); Zanetti et al., (2016); Karagiorgos et al., (2016); Fernandez et al., (2016).

(3) Social references: Esmaeili, V. (2014); Carreño et al., (2011); Uejio et al., (2011); Rufat, S. (2012); Tilio et a., (2012); Chen et al., (2013); Ahmad, S. S., & Simonovic, S. P. (2013); Alguacil Gómez et al., (2014); Temes, R. R. (2014); Fang & Wang, (2015); Lemonsu et al., (2015); Kotzee, I., & Reyers, B. (2016a); Takagi et al., (2016); Bradfordet al., (2015); Kumar et al., (2016); Martin, (2015); Koks et al., (2015);

Table 2.3 Description of urban vulnerability assessment methods.

Taking account of their means and standard deviations (SDs), Table 2.3 Description of urban vulnerability assessment methods.reveals an increasing relevance (higher mean), for the latter years, of assessments dealing with the infrastructure-related stimuli, which are water flooding, storms, surface infrastructure failures and underground infrastructure failures, the latter being prone to social approaches. Table 2.3 Description of urban vulnerability assessment methods. also displays the affinity of the "seismic" and "surface infrastructure failures" stimuli for the biophysical methods (lower approach mean).

Having resulting a p-value of 0,093 in the Welch’s test, one way anova (90% CI) between approach and developmental stage revealed a significant influence of the former on the latter, in such a way that the comprehensive approaches directly promote an increase in developmental stage towards the adaptation stage (Figure 2.1), while the biophysical approach underpins that of the impact stage.

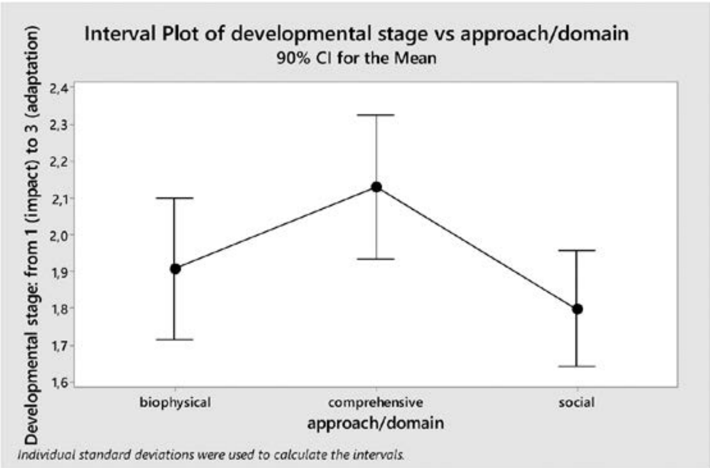

Figure 2.1 Influence of approach on evolutive stage.

Table 2.3 shows that the development course is stalled within the vulnerability assessment stage, in which social approaches play the most important role.

However, a slight, yet non-significant increasing trend of the relative importance of the adaptation and, to a lesser extent, impact stages, can be perceived from 2014 onwards (Figure 2.2). This may be explained by the previously stated relations between, on the one hand, infrastructure- based stimuli with the biophysical and comprehensive approaches, and on the other hand, biophysical and comprehensive approaches with the impact and adaptation stages, respectively.

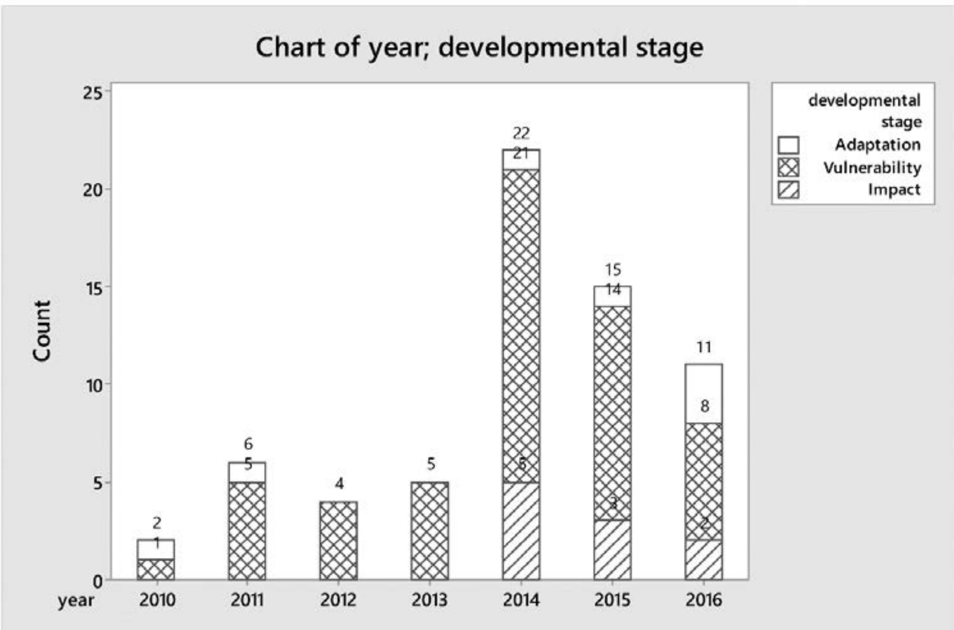

Figure 2.2 Studies per evolutive stage and year.

2.5.2 Research effort made

In this section, effort made in the research of UVA methods is evaluated by means of a descriptive analysis, firstly, of the number of requirements tacked by the papers reviewed, and secondly, of the overall attributes mentioned in section 3.1.

2.5.2.1 Number of requirements

The ratio of undertaken requirements was 0.54 per assessment method reviewed, as shown Table 2.4. It can also be observed that most of urban vulnerability assessments were related to robustness and the cognitive-cause effect, while the presence of the other requirements is far lower. Table 2.4 "Relative (2)" column makes explicit this heterogeneity, encouraging further analysis of its inner structure.

	count	%	
		Absolute (1)*	Relative (2)*
(1) assessment methods fully reviewed:	65	100	
(2) assessment undertaking requirements	35	54	100
robustness-uncertainty	17	26	49
participatory-subjectivity	11	17	31
multi scale-complexity	3	5	9
dynamic nature	4	6	11
multi objective-strategic capacity	3	5	9
cognitive-cause effect	13	20	37

* Note: Absolute (1) and Relative (2) are percentages respectively referring to all UVAs reviewed, and to exclusively those also undertaking requirements

Table 2.4 Urban vulnerability assessment research requirement types.

For the purpose, a clustering approach upon the basis of the number of observations, whose results are shown in Figure 2.3, was carried out. Three clusters, referring on the one hand to the attention paid to each research line, and on the other hand to the similarities in their behavior, were identified.

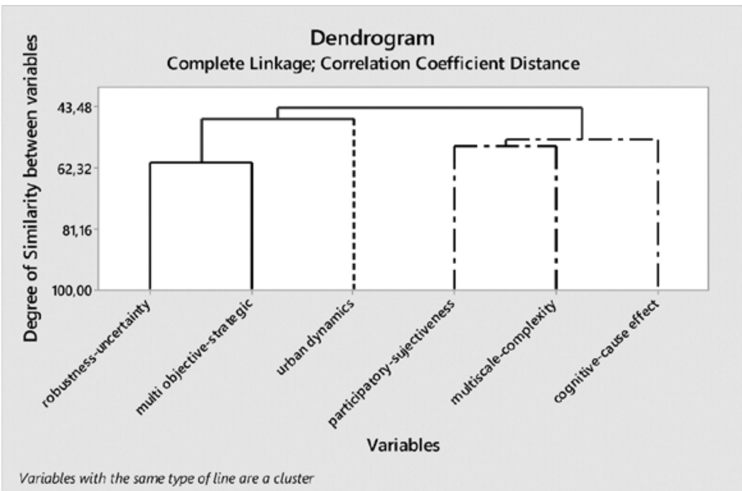

Figure 2.3 Cluster result.

Nearly half of the reviewed publications do not aim at the attainment of any of the identified research requirements (Table 2.5).

number	count	%
0	30	46
1	22	34
2	10	15
3	3	5

Table 2.5 Assessments per number of simultaneously undertaken requirements.

Furthermore, they present a very low performance when it comes to incorporating various requirements at once, with a maximum of three. This states a low level in methods seriously attempting to embrace many of the previously highlighted aspects, and thus a poor performance when it comes to taking advantage of the foreseeable profits that are to be expected from an integrated effort (Romero Lankao & Qin, 2011). Given their means and standard deviations, Table 2.3 reveals that assessments bearing no research requirement are confined within the vulnerability assessment stage (mean below 2 and lowest SD), while those embodying two or more tended to adaptation (higher means and SD).

2.5.2.2 Generic attributes

Bearing in mind both the time trends as the activity displayed in relation to the requirements achievement, four groups can be inferred from Table 2.6, i.e. continuously active, discontinuously active, continuously passive and discontinuous passive, trends. The first is characterized by an important growth from 2012 to 2014, sustained thereafter, encompassing the robustness and cognitive requirements. The second, which refers to the participatory, experiences a sudden and pronounced increase from 2013 to 2014, disappears in 2015 only to rise again in 2016. The third group is composed of the requirement urban dynamics, and its lines show an almost constant behavior, as well as a low activity. Finally, the fourth group, which represents the multi scale-complexity and multi-objective requirements, is almost unnoticed until 2013, with an unexpected and weak appearances in 2014, and two and one more observations respectively in 2016. Despite the low amount in the number of studies, an increase in the presence of research requirements was detected for the later years.

Table 2.6 portrays the relationships between the aspects ‘research requirements’ and ‘approach’, stating that it is the biophysical and comprehensive approaches whence the greater research effort comes, especially for the robustness-uncertainty, and cause-effect research lines respectively.

	research requirements						
aspects	Robustness/uncertainty	Participatory/subjectivity	Multi-scale/complexity	dynamic nature	Multi-objective-strategic/capacity	Cognitive/cause-effect	total
Count	17	11	3	4	3	13	51
(1) %	33	22	6	8	6	25	100
(2) Mean along	41,744	41,905	42,127	41,457	41,640	41,752	
(3) Std along Year	631	567	421	966	365	524	
(4) Trend =	8.6E6	5.2E6	1.0€6	3.2E6	0.1E6	5.4E6	
Year:							
2010	1	0	0	1	0	0	2
2011	2	1	0	0	0	1	2
2012	0	0	0	0	0	0	0
2013	2	0	0	1	1	2	6
2014	3	4	1	0	1	4	11
2015	5	1	0	1	0	3	
2016	4	5	2	1	1	3	11
Approach:							
biophysical	10	3	1	1	2	3	20
comprehensi	4	5	1	2	1	6	19
social	3	3	1	1	0	4	12
Evol. Stage:							
impact	4	2	1	0	0	1	8
vulnerability	9	7	2	3	2	9	32
adaptation	4	2	0	1	1	3	11
Stimuli:							
natural	5	3	1	1	0	2	12
seismic	3	3	1	0	2	5	14
water	6	3	1	3	1	3	17
social	0	2	0	0	0	1	3
underg.	1	0	0	0	0	1	2
surf. Infras	2	0	0	0	0	1	3
Simultaneous req.:							
1	7	5	1	2	1	6	22
2	7	4	1	2	1	5	20
3	3	2	1	0	1	2	9
all	17	11	3	4	3	13	51

Table 2.6 Description of research requirements undertaken by urban vulnerability assessment methods.

Table 2.6 gathers the number of research requirements in terms of stimuli, so that two groups were identified: the first composed of those stimuli in which the sum of all pursued requirements is between 2–3 observations, and a second in which the sum ranges between 12–14-17 (natural generic, seismic and flooding respectively). Otherwise, water flooding was the only hazard whose dealing had promoted all research requirements, closely followed by the seismic and natural generic stimuli, these latter being present in four of the five research directions. This, together with the fact that they had more observations in terms of research requirements, evidences that natural generic, seismic and water flooding-storm were, for the short term, the type of stimuli where most progress, in terms of research intensity and diversity, was to be expected. As far as the future is concerned, however, the so-called infrastructure-related stimuli yielded better prospects, due to their increasing ascendancy.

2.6 Analytical framework and discussion on the advancement made

In this section we assess to which extent, the requirements arisen for UVA in the light of the advancement made on USP, have been operationalized on the former. For the purpose, firstly an analysis and consequent discussion of advancement made for each of the research lines (section 2.3.2) was conducted, and secondly a description of the relationships linking the research with the generic attributes (section 2.3.1) was provided.

2.6.1 Analysis of each research attribute

2.6.1.1 *Robustness*

Robustness is the most frequent requirement (Table 2.6) across all developmental stages, and also in the two main approaches. Additionally, from 2010 to present, except in 2014 and 216, robustness was observed the most, exhibiting an active and continuous behavior (Section 5.2). Therefore robustness is currently the main research line in the field of UVAs.

Table 2.7 provides insights for qualitative analysis of the state of robustness. Robustness-related studies were grouped according to the technique used to model uncertainty, and classified into the following categories: incremental, modeling-managerial or discursive approaches (Dominguez et al., 2011). Most of the studies addressing uncertainty were simulation-based, i.e. they attempt to reproduce the real world. Of these, 12% were based on complex network models such as cascade-failure methods (Sun et al., 2015), focusing on the relations between discrete objects within a network, while 6% employed fuzzy set theory to build a probabilistic model based on the load and resistance principle from reliability engineering. 24% used other types of models, such as a combination of the probabilistic method and statistical models, or the project pursuit approach.

	Uncertainty approaches						
	incremental	modeling	managerial	discursive	total		
model	no scenario	no scenario	no scenario	scenario	count	%	references
simulation	0	5	1	4	10	59	Kaji et al., 2014; Kirshen et al., 2015; Takagi et al., 2016; Bristow & Brumbelow, 2013; Lemonsu et al., 2015; Aina & Aleem, 2014; Giardina et al., 2015.

complex network/cascade failure	0	0	2	0	2	12	Yuan et al., 2014; Sun et al., 2015
fuzzy	0	1	0	0	1	6	Ahmad & Simonovic, 2013
other	4	0	0	0	4	24	Chiauzzi et al., 2011;Zhang et al., 2013
total count	4	6	3	4	17	100	
total %	24	35	18	24			

Table 2.7 Studies dealing with uncertainty.

Scenario planning, which is considered to be adequate for handling future uncertainties (Dominguez et al., 2013) and falls within the integrated strategic planning context (Malekpour et al., 2015; Dorning et al., 2015), was commonly used, accounting for 25% of the studies fostering uncertainty. The former technique, when combined with cognitive approaches, relates to the discursive stage (Bristow & Brumbelow, 2013; Giardina et al., 2015; Lemonsu et al., 2015). Complex network models, which is akin to an uncertainty managerial approach, allow nodes to be assigned with certain degrees of freedom, were also commonly found. The use of simulation-based models was found to be most extensive in studies from 2012 onwards. Modeling uses fuzzy set theory to perform probabilistic-based models. Sensivity analysis had also been used for robustness assessment (Marull et al, 2007).

***2.6.1.2** Participatory*

Despite the important interest that arose from this requirement (22% of Table 2.6 total share), from a qualitative point of view, the employment of the participatory process for grasping subjectivity is shown to be rather immature and lacking in steadiness. However, due to its strong involvement in assessment methods disclosed in 2016 bearing multiple requirements, its performance was good when it came to integrating this requirement with others.

From the stimuli point of view, this requirement is untold among UVAs dealing infrastructure-related stimuli. Alguacil Gómez et al. (2014) and Lee et al. (2009) proposed methods aiming to grasp the subjective side of urban vulnerability, i.e., how people experience change (Adger, 2006), by considering the assessment of indices intended to quantify that subjectivity. However, in this study, the assessment is obtained exclusively from the opinion of the head of the area of urban planning in each of the municipalities analyzed, rather than from people who came from vulnerable sections themselves (Adger, 2006). Kimani-Murage et al. (2014) went a step further by putting forth a more extensive survey in order to assess how the affected inhabitants defined, perceived and experienced crisis. Another qualitative step forward was taken by Moradi et al. (2014) when assessing the degree of subjectivity in expert judgement, and its possible influence on the decision-making process. The latter is an important issue due to the fact that taking into account the participatory process is a necessary, but not a sufficient condition (Munda, 2004), and thus some kind of weighting should be provided to allow for aggregation of the results provided by participatory processes. The majority of the other studies assessed make a basic use of participatory processes, incorporating experts to the evaluation process when using a qualitative approach, or have to weight variables.

These advances, however, fail to bridge gaps like a lack of processes for identifying all critical stakeholders rather than only those of the vulnerable sections (de Graaf & Dewulf, 2010), and the pending development of tools for channeling public participation into assessment processes (Shiehbeiki et al., 2014). This leads to the assertion that the participatory-subjectivity requirement, despite having theoretical foundations for its proper development, is disconnected from the trend at the forefront of urban vulnerability research. The implementation in UVA methods of participatory processes entailing high stakeholders and citizen involvement would help reverting this situation first by incorporating the social point of view, second by providing the required consensus on the weighting scores needed to start-up the vulnerability assessment process, and last by furnishing the evaluation process with the required feed-back. This way, representation and legitimacy will be guaranteed on the process, which becomes truly bottom-up. To this, the development of other research lines can also contribute by providing the stakeholders with an enriched knowledge though the employment of multi-objective as a cognitive approach.

2.6.1.3 *Complexity-multiscale*

With only a 6% total share, from a quantitative point of view, the "complexity-multiscale" research line, together with that of multi-objective, received the least research interest. Having appeared just three times (Koks et al., 2015; Rosenzweig et al., 2011; Shuang et al., 2014), neither a yearly, nor other trends can be clearly inferred, as shown in Table 2.6. It is surprising that, although existing references point out its importance for both UVA (Adger, 2006; Romero-Lankao et al., 2014) and USP (Giezen et al., 2015; Pemberton & Searle, 2016; Lundqvist, 2016; Carmo, 2013; Toubin et al., 2015), so little attention has been paid to multi- scale. Furthermore, as trans-disciplinary approaches are proper for tackling complexity (Smith & Jenkins, 2015), this lack of integration suggests that its research strategy is misled. Several techniques for dealing with complexity and multi-scale, such as Monte- Carlo simulation, spatial auto-correlation (F. Dormann C. et al., 2007; Uejio et al., 2011), some simulation-based techniques such as survival analysis combined with cellular automatas (Chen et al. 2016), the syndrome approach (Romero Lankao & Qin, 2011) or cascade-failure methods (Sun et al., 2015), which have already been used in field of USP, can help remedy this undesirable situation.

2.6.1.4 *Urban dynamics*

The cluster analysis displayed in Figure 2.3 reveals that this requirement, stands alone forming the under-researched group. Besides, it shapes the continuously passive behavior group identified previously. Table 2.6 shows that water flooding-storm stimuli are those most akin to dynamic nature research, and points out similarities between dynamic and multi-objective both in the number of observations and in integration. It is present both for every approach, and, as multi-objective, mainly in the vulnerability assessment, but in the adaptive assessment developmental stages. Dynamic programming, fuzzy logic and simulation-based optimization models have been used by some of the methods reviewed to deal with the dynamic nature of some environments (Juan et al., 2015), as well as combining linear programming with genetic algorithms (Long & Li, 2014). Multi-objective optimization techniques, such as genetic algorithms, have been used in urban vulnerability research to deal with uncertainty (Bristow & Brumbelow, 2013), an advance to which the 'dynamic nature' research line has not yet joined. Ahmad et al. (2013) made an attempt to grasp the dynamic nature of urban systems by focusing on the dynamic state of a system, i.e. on the balance relation between the so-called theory of load and resistance forces, which can ease or oppose to changes to be accepted in a system, respectively. In any case, due both to the importance attributed to dynamic nature and to its low-to- medium quantitative profile, our assessment considers the progression made to be insufficient. This is a somewhat limited advance from the situation depicted by Pamungkas (2013), when this worker stated that there had been no progress in this research line at all.

2.6.1.5 *Multi-objective*

The multi-objective research line showed several similarities with robustness. As can be observed in Table 2.6, the sorting of approaches, from major to minor, by number of cases (biophysical-comprehensive-social), turned out to be the same for both. For both of them, as well, the seismic and water-flooding stimuli were the main ones. On the other hand, robustness and multi-objective differ significantly in one aspect, namely the proportion of effort bestowed to them (Table 2.6). Notwithstanding this difference, similarities prevail sufficiently as to form a cluster, composed of multiobjective, robustness and cognitive requirements, referred to above as the highly researched cluster (Figure 2.3).

In two of the three studies where the presence of multi-objective research lines was detected, MOO algorithms were incorporated into approximate solutions: In Esmaeili (2014) and Bristow & Brumbelow (2013) respectively, MOO-genetic algorithms and simulation techniques were combined to also deal with uncertainty, thus belonging to the so-called sim-heuristics techniques. The latter embody both simulation and heuristic optimization, whose capacity for dealing with real-life uncertainty is regarded as proven (Juan et al., 2015). The evaluation method proposed by Bristow & Brumbelow (2013) confirmed this synergy between heuristics and simulation, and presented advances in the 'robustness-uncertainty' related research line. Therefore, it can be concluded that the 'multi-objective-strategic capacity' research requirement presents medium-low and medium-good performances from quantitative and qualitative perspectives, respectively.

2.6.1.6 *Cognitive*

In Table 2.6, the cognitive requirement is ranked second in terms of qualitatively leading the research lines across all developmental stages, as in most approaches. The yearly distribution showed an important increase in 2013, which had been sustained through 2014, 2015 and 2106, following almost the same trend as robustness. It has been mainly applied to deal with the seismic and natural general stimuli, appearing integrated in a third of its observations; consequently, this requirement ranked second in terms of integration capacity. Furthermore, its combination with other research lines led to a qualitative increase in the latter, as in the case of discursive approaches for dealing with uncertainty (Dominguez et al., 2011). Examples of this were found among the studies reviewed. Giardina et al. (2015) embodied both cognitive and robustness requirements, while Bristow & Brumbelow, (2013) embraced the requirements of robustness, multi-objective and cognitive, to perform the most integrative method. Also noteworthy is that cognitive, along with the robustness requirement formed the so-called continuously active (section 5.2), and is also related with the also highly researched participatory requirement (Fig 2.3, dot and Dash line). This provides evidence not only of the significant attention paid to this requirement, but also of the synergistic relation between "robustness" and "cognitive", easing discursive approaches to which multi-objective can also contribute (Yepes et al., 2015).

2.6.2 Relationships between research and generic attributes

As to the relationship between research requirements and the generic characteristics defined in section 3, Table 2.6 also depicts the attention paid to each requirement by the developmental stages, highlighting robustness, participatory and cognitive as the most attractive for researchers of whatever developmental stage, especially for those of vulnerability assessment. From this table we can infer, besides, that those two requirements are also highly correlated with the group of those stimuli amounting the greater number of observations, composed by the stimuli natural generic, flooding and seismic.

Regarding the relation of requirements with the type of approach, most of them were equally spread among all approaches. On the contrary, research on robustness, and to a lesser extent on multi-objective, were distinctly showing their reliance on the biophysical approach for the developed by now attained. Therefore, considering on the one hand that biophysical approaches underpinning robustness are showing an increasing trend, and on the other hand that the robustness requirement is among the requirements identified in the research effort section as exhibiting an active behavior (section 2.5.1), the better prospects can be expected for the development of more research on this issue. It is pending, yet, furthering in its implementation into UVAs arisen from socio-economic or comprehensive approaches.

2.6.3 Policy implications

Given the leading role of infrastructure-related UVAs, we suggest policy-makers to boost this trend by promoting the incorporation of UVA methods within the infrastructure planning process. Given the close connection between UVA and USP evolutions, that incorporation would be a natural way of contributing the advancement of UVA research.

On the other hand, by following our suggestions UVA methods will be ensued that affords policy-makers with comprehensive assessments in which the different socio-political scales conforming a territory are linked. This, on the one hand, will enable policy-makers to rise plans, coordinated throughout scales, in which entities ranging from national to municipal scales are evaluated under a same model.

Finally, to convey those plans across institutional scales, however, may require the adoption of new policy measures. This task may be facilitated by the adoption, in the development of the assessment model, of bottom-up strategies, which the current UVA trend advocates since it promotes:

- Citizen and stakeholder involvement by which to ensure representation and legitimacy, and soften the implementation of plans.

- The incorporation of methods fostering robustness, as a way for dealing uncertainty, in which stakeholders are taken into account at the beginning of the process.

- Multi-Objective modelling accounting for stakeholders' interests, to embody the Cognitive approach providing stakeholders with a better understanding of the model.

- The consideration of the multiple socio-political scales embodied in a territory and their linkages, thus providing a transmission chain along institutional scales from bottom to top.

2.7 Conclusions

First, this paper traced a common evolutive path for both urban strategic planning and urban vulnerability assessment, with the former paving the way. This path runs through a series of waypoints, in the form of research requirements that are shared by both strategic planning and vulnerability assessment. Six common research objectives (viz. increase of robustness, for dealing with uncertainty, embodiment of participatory processes to grasp subjectivity, consideration of the multiscale and complex nature of the subject as well as its dynamic character, account for multiple objectives to gain strategic capacity and to implement cognitive outlooks that can provide insights of cause-effect relations) are generalized from this track.

Secondly, upon the basis of the above, an analytical framework considering other relevant aspects, such as the types of stimuli that occur, approaches that deal with them, and the developmental stage, is formed to evaluate the current state of the advances made in the assessment of urban vulnerability. Thirdly, for the purpose of grasping current trends in research, a review of the studies related to urban vulnerability from 2010 onwards was conducted, upon which an evaluation grounded in the aforementioned analytical framework was developed. Its main findings, attempting to evaluate current advances, are the following:

- With almost half of the analyzed studies undertaking any research requirements, and a significant decrease in its number, the UVA methods' quantitative prospects do not promise an increase in interest in the subject, nor advances in its developmental stage, but rather a stagnation. This means a setback with respect to trends identified in 2011, when growing interest was foreseen (Romero Lankao & Qin, 2011; Tonmoy et al., 2014); This, in fact, was sustained until 2014, but is absent today. However, the number of studies regarding the so-called infrastructure-related stimuli, arising mainly from the biophysical domain, prevail, and are consequently gaining ground within the UVA field (section 2.5.1), thus increasing the overall research performance (Section 2.5.2).
- Due both to the heterogeneity in the attention paid to them and to similar behaviors, the identified research lines can be grouped into a first, second and third cluster,

recording significant, limited and almost null advances respectively (Table 2.8). The first embraces those requirements arousing the most interest (Table 2.6), relating mainly to methods simultaneously embodying multiple research lines and, in the case of robustness and cognitive, whose qualitative development is not far from that of strategic planning. The second performs low-to-medium/good in a quantitative and a qualitative sense respectively, and is composed of the multi-objective alone. Finally the third, involving the urban dynamics and complexity-multiscale requirements, to which less attention was bestowed, yields a medium-to-low performance in proximity to the strategic planning advances.

	Quantitative (1)		Qualitative (2)		Overall (2)
requirements	% research effort	present trend	proximity to strategic planning	multiple requirements	advancement
robustness-uncertainty	good	good	good	good	significant
participatory-subjectivity	medium	medium	medium	low	significant
multiscale-complexity	low	low	low	low	almost null
urban dynamics	medium	medium	medium	medium	almost null
multi objective-strategic	low	low	medium	good	limited
cognitive-cause effect	good	medium	medium	good	significant

Note: Criteria for clustering into classes good, medium or low:
(1): % of UVA methods and value of Trend in Table 2.6
(2): Assessment in section 6, Analytical Framework.

Table 2.8 Evaluation of the advancement made on urban vulnerability assessment methods.

- The 'approach/school of thought' aspect, whose biophysical and comprehensive levels promote the impact and adaptation stages of UVA's evolution respectively, significantly influences the latter.

Thirdly, the relations identified allow us to envisage a desirable future taking the UVA out from its current evolutionary stagnation, promoting more integrative methods and embodying those requirements more akin to comprehensive approaches. In order to reach it, assessment methods not limited to but especially fostering research on cognitive, multi-objective and under-researched requirements should be encouraged. As well, the promotion of methods incorporating uncertainty into social and comprehensive approaches is still pending, and therefore deserves more research effort. Since USP largely provides the required tools and can develop new ones, and that the proposed scenario implies a qualitative swap rather than a quantitative increase, this can and should be attained. Therefore, a shift in the research focus, bridging the detected qualitative gaps and driving progress in the evolutionary scale, should be set up. Due to their good performance in their capacity for bearing simultaneously multiple research lines, and to their growing importance for the research community, the assessment methods related to "water logging and storm", "underground infrastructure failure" and, to a lesser extent, "surface infrastructure failure" are called upon to lead the future advances.

Thus, for the purpose of and with the aim of taking advantage of their growing ascendancy, this paper encourages all workers in this field, but especially those developing urban vulnerability assessments on infrastructure-related stimuli, to enhance their methods through a shift in their focus towards the integration of specially the cognitive, multi-objective, complexity-multiscale and dynamic research requirements described in this work., and by the adoption of advanced methods dealing with uncertainty. This way, they may capitalize our findings by achieving more advanced UVA methods which, on the other hand, would also profit policy makers and planners due to the improvement of knowledge entailed by the cognitive approach promoted in our work.

Notwithstanding the amount of papers analyzed, the scope of this research, focused on works carried out from 2011 onwards and hence representing a tip of the iceberg on this topic, impose limitations on the concretion level of the possible conclusions. Therefore, the assertions made should be understood rather as guidelines based on the identified current trends, than as concrete measures.

Besides, the qualitative part of the analysis mainly relies in an overall, instead of case-by-case, assessment of each research line. In consequence, the promotion of complementary works taking a deeper look on each research line, by means of a deeper analysis of their qualitative development within a narrower span of time, appears as of necessity for the proper implementation of such requirements on UVA methods.

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Capítulo 3

A method for selecting Urban Vulnerability Assessment Models - Metodología para la selección de Modelos de Evaluación de Vulnerabilidad Urbana

Artículo 2: A discursive, many-objective approach for selecting more-evolved urban vulnerability assessment models

Publicación

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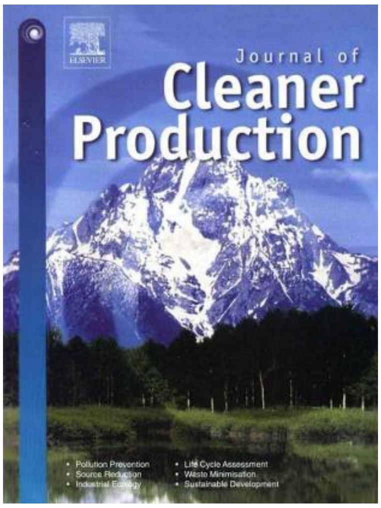

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Abstract: The development of more-evolved urban vulnerability assessment (UVA) models has become an increasingly important issue for both policy agendas and academia. Several requirements have already been set for this goal; they should be pursued simultaneously. However, methods with such integration are yet to be developed. The present paper addresses this integration via a discursive process in which interactions between decision makers and the method contribute to the selection of a model fulfilling these requirements. That model yields a UVA built upon both qualitative information and quantitative data from indicators selected for the neighbourhood, city, province, region and country political-administrative scales. The characteristics demanded are encoded both into the UVA assessment model and in the optimization and control modules governing the process. While the optimization produces compromise solutions, the control module supervises the process, provides dynamic control and enables the interactions. Interactions are informed with knowledge derived from the cognitive approach entailed by the method and afford a better understanding of the process dynamics. We conclude that the goodness of fit and time dynamics objectives are aligned. Therefore, UVA methods performing well for these objectives are available, although at the expense of medium to poor preferences and robustness of performance.

Keywords: urban vulnerability assessment, discursive approach, many-objective optimization; cognitive approach.

3.1 Introduction

Urban vulnerability (UV) in general and its adaptive component in particular have become key issues for urban strategic planning (USP) (Rigillo & Cervelli, 2014) with the aim of achieving sustainable development (Malekpour et al., 2015) and coping with climate change (McCarthy, 2001; Turner et al., 2003; Adger, 2006; Chang & Huang, 2015). Specifically, improvements of adaptive governance and strategic planning in the context of climate change and socio-economic transformation are demanded (Birkmann et al., 2014). As a consequence, methods that assess vulnerability are increasingly being developed for countries around the world (Fekete, 2009).

The IPCC Assessment Report (McCarthy et al., 2001) defines vulnerability as follows:

"*The degree to which a system* (entity) *is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.*"

This concept is, to a high degree, negatively correlated with that of resilience (Adger, 2006), whose improvement is in turn considered essential by USP for the sake of urban sustainability.

Nevertheless, there are many other definitions that challenge current thinking, to the extent that it is necessary to perform research specifically aimed at conceptual clarification (Füssel & Klein, 2006; Wolf et al., 2013), which exceeds the scope of this study. A few aspects, however, are beyond question, the first being that vulnerability should be assessed with regard to not only its current state alone but also its future risk, and the other being the attributes demanded by the research community for the assessment of this concept.

Concerning the first aspect, several authors have pointed out the dynamic character of vulnerability over time and that, in consequence, along with the current state of vulnerability, the risk of becoming (more) vulnerable also needs to be measured (Adger, 2006; Birkmann et al, 2014; Füssel, 2007; Nahiduzzaman et al., 2015). Therefore, "*the ability to monitor and anticipate vulnerability would be a public good for all potentially affected places and systems*" (Stern et al., 2013, pg. 609) and can help solve resource-allocation problems (King & Blackmore, 2013; Nahiduzzaman et al., 2015; Rigillo & Cervelli, 2014) by providing prioritization guidelines. According to Brooks (2003), a quantitative assessment of risk is desirable in order to develop integrated vulnerability assessment models. However, there are not many examples of how to conduct such assessments on a quantitative footing (Birkmann et al., 2014; Lummen et al., 2014). In the particular case of UVA, models quantitatively assessing risk are yet to be developed.

As to the second aspect of vulnerability, the attributes demanded are robustness as a way to cope with uncertainty (Dominguez et al., 2011; Hall et al., 2012; Malekpour et al., 2015),use of cognitive approaches (Mustafa et al., 2011;Yepes et al., 2015; Pamungkas et al., 2014), a better understanding of UV dynamics over time and political-administrative scales (Adger, 2006; Birkmann et al., 2014; Liu el al., 2010; Pamungkas et al., 2014), and having a strategic, multi-objective capacity to avoid eventual tunnelling effects and to improve the system's adaptive capacity (Munda, 2004). Also, it is necessary to account for the subjective and complex nature of urban vulnerability (Adger, 2006).

Previous works have pointed out the need to develop methods that integrate most of these research requirements in order to advance the field of UVA assessment methods towards the discursive stage in urban strategic planning. This stage represents the latest trend in this field (Dominguez et al., 2011; Malekpour et al., 2015) and conveys the adaptive policy capacity demanded to face system's vulnerability (Adger, 2006; Fussell & Klein, 2006). Although works dealing with these requirements separately have already been developed, a UVA method integrating them all is still lacking.

On the other hand, in spite of the amount of works pointing out the importance of the dynamic nature of urban vulnerability across its multiple scales (Adger, 2006; Giezen et al., 2015; Lundqvist, 2016; Pemberton & Searle, 2016; Romero-Lankao & Qin, 2014; Toubin et al., 2015), there is still a gap in the development of quantitative models for the assessment of UV that take into account the multiple political-administrative scales in which entities are contextualized.

The integration of methods addressing the research requirements may be achieved by means of multi-objective optimization modelling methods that encode the research requirements in objectives such as robustness of the model (as opposed to its sensitivity) or goodness of fit (Boada et al., 2016). These objectives work as the attributes that define the behaviour of the model.

Optimization modelling has been previously employed to deal with problems concerning urban management. Among those techniques, genetic algorithms are robust and efficient heuristic algorithms for solving problems defined by urban vulnerability assessment (UVA) methods and for looking for solutions in large, complex, non-linear and little-understood search spaces. This method has already been proposed for addressing unstructured urban issues and multi-objective land-use planning problems, as well as in the development of more sustainable strategies (Martí et al., 2016; Mousavi-Avval et al., 2017; Zhang & Chiong, 2016).

The objective of this paper is to present a new method, embodying the attributes demanded for UVA, that is capable of selecting an optimized urban vulnerability assessment model by assessing, on a quantitative footing, the current State and the future Risk of Urban vulnerability on the basis of both the available socio-economic indicators and expert preferences. To obtain the optimal satisfaction of the attributes demanded by both USP and UV research, this method was designed, by means of its optimization module, to maximize the subjective preferences expressed by practitioners (DO-1, Figure 3.2), maximize the robustness of UVA models (DO-2, Figure 3.2), maximize their overall goodness-of-fit (DO-3, Figure 3.2), maximize the similarity among indicators of different political-administrative scales and the dynamic connection over time (CO-1, Figure 3.2), and maximize the goodness of fit at each scale (CO-2, Figure 3.2). Moreover, while other assessment models fail to take into account, when assessing vulnerability, of the linkage between political-administrative scales, the method designed relates them in the quantitative assessment framework, thus incorporating the context-dependent character of urban vulnerability. On the other hand, its control module allows interaction (I-1 to I-3) between practitioners, decision-makers (DMs), and the model while providing trade-offs between objectives. From these trade-offs, guidelines can be elicited which, together with the participation of the DMs in the process, furnish these latter with an improved knowledge of the problem at issue (Torres-Machi et al., 2017), enabling them to carry out an informed selection.

Therefore, the novelty of the method presented mainly relies on the following aspects: first it enables DMs, through a process embodying the abovementioned attributes, to make an informed selection of a UVA model; second, it provides a quantitative assessment of both the state and risk of UV; and finally, it takes into account, within the qualitative assessment framework, the multiple scales shaping the political-administrative context of the entities within the area evaluated.

The remainder of this paper is organized as follows. In the methods section, the general workflow describing the relation between the control and optimization modules and the quantitative framework, as well as a detailed description of these three modules, is presented. The methodology proposed is applied to an actual case in the case study section, and the results are presented and discussed in the subsequent section. Finally, general conclusions are drawn in the last section.

3.2 Methods.

This section describes the whole process, analysing its elements one by one as indicated in Figure 3.1. We begin describing how the process works in general and then, for each of its stages, detailed explanations are given.

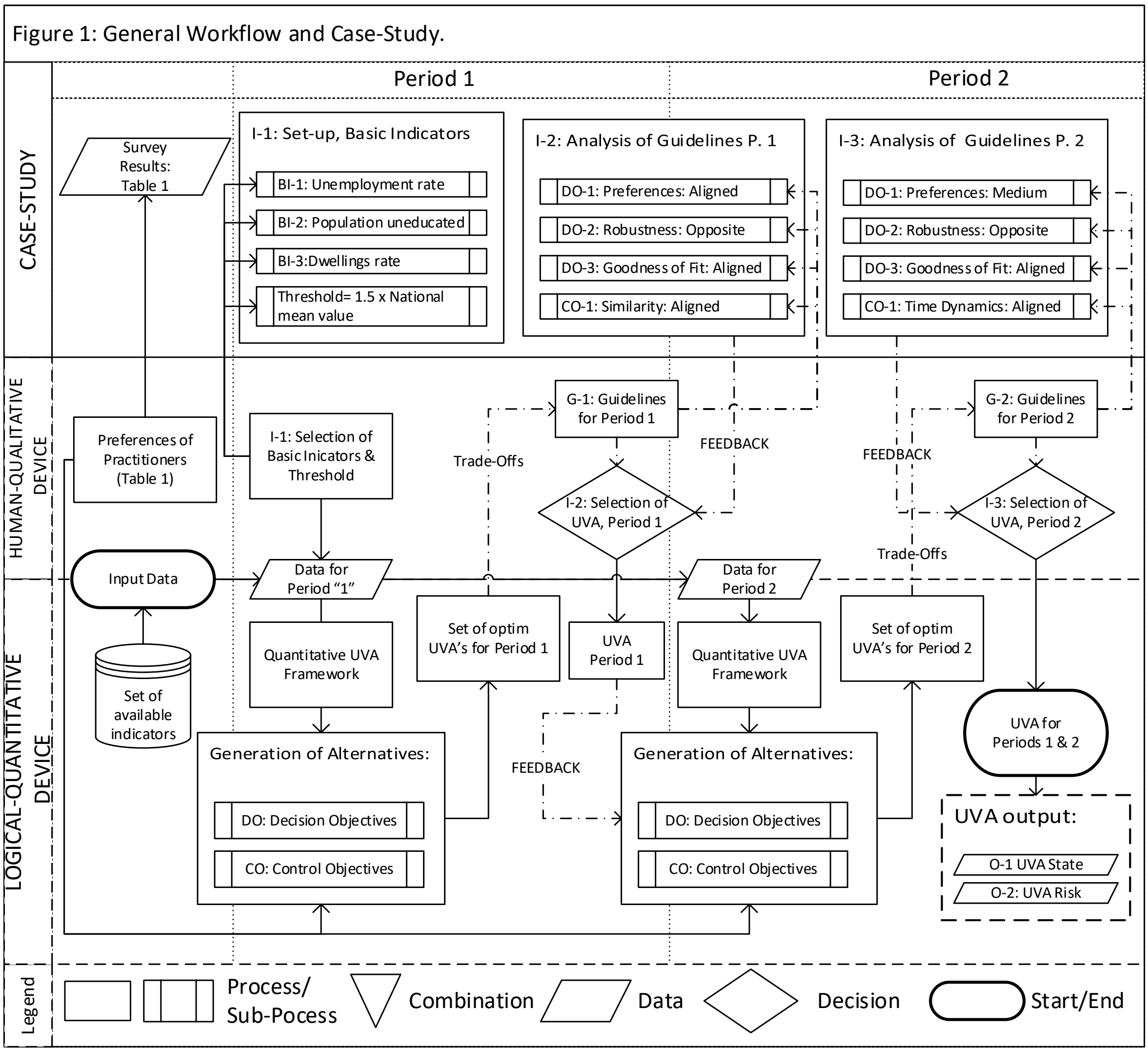

Figure 3.1 Method for selecting UVA models, General Workflow and Case-Study.

3.2.1. General Workflow:

For UVAs, satisfying the abovementioned requirements means integrating them into a framework. For this purpose, a general workflow comprising three modules, namely the Assessment, Optimization and Control modules (Figure 3.1), was designed. The Assessment Module, which is the UVA model itself, undertakes accounting for subjectivity and for the dynamic character of urban vulnerability. The second module, namely the optimization model, contributes toward handling the many-objective, multi-scale, cognitive and robustness requirements by encoding them into the optimization objectives. In addition, both its subjectivity and its dynamic nature should be considered, which has been addressed by embodying these features in the former modules and by running the general workflow through a discursive approach (Dominguez et al., 2011). The latter took form as the Control Module implementing an iterative dialogue between the DMs and the model.

The idea is to elicit general guidelines by following a three-step process. In the first step, the quantitative and qualitative information required by the UVA Assessment Module (Figure 3.1, 2.1) is obtained. Then, the Assessment Module is executed and, in a second step, a set of Pareto-optimal models (Figure 3.1, S-1 & S-2) is elicited through the Optimization Module (Figure 3.1, 2.2). As the third step, the Control Module allows for the inference of the guidelines for the selection of a characterization model (Figure 3.1, G). Steps 2 and 3 are repeated for every subsequent period.

3.2.2. Control module (Figure 3.1, 2.3)

The control module implements the discursive approach, and operates upon the Optimization and the Assessment modules by implementing three main interactions (Figure 3.1): **I-1**, introducing a set of basic conditions, the entities to be classified as vulnerable or non-vulnerable, into the assessment model; **I-2**, choosing an initial model, via the designed characterization framework, capable of achieving the desired behaviour in terms of robustness, subjective preferences and GOF; and **I-3** giving continuity to the starting model by selecting that of the subsequent period. For each entity, year and period, the UV State and Risk were assessed, allowing its integration in strategic planning processes.

The interaction **I-1** implies that the whole model will be built under some basic, subjective assumptions relating both to criteria used for the basic evaluation and its thresholds. In addition, since the second and third interactions require the selection of one model from many models via DMs, subjectivity is also present in those stages. Nevertheless, though improvement in objectivity should be pursued to satisfy the already noted UVA requirements (Munda, 2004), a certain degree of subjectivity is unavoidable, and therefore acceptable in the field of vulnerability assessment methods (Solín, 2012).

3.2.3. Optimization module (Figure 3.2, 2.2)

The problem of the modelling system's behaviour was addressed via the multiple objectives the optimization model sought to achieve (Boada et al., 2016). Therefore, with the aim of fulfilling the already-stated requirements for UVA methods, the behaviour was evaluated in terms of the preferences of practitioners as the required aggregation of external judgment (Adger, 2006), robustness (Hermeling et al., 2013), and GOF (Boada et al., 2016), each of these being an objective in the optimization process (Figure 3.2, DO 1 to 3; Table 2, f obj 1 to 3).

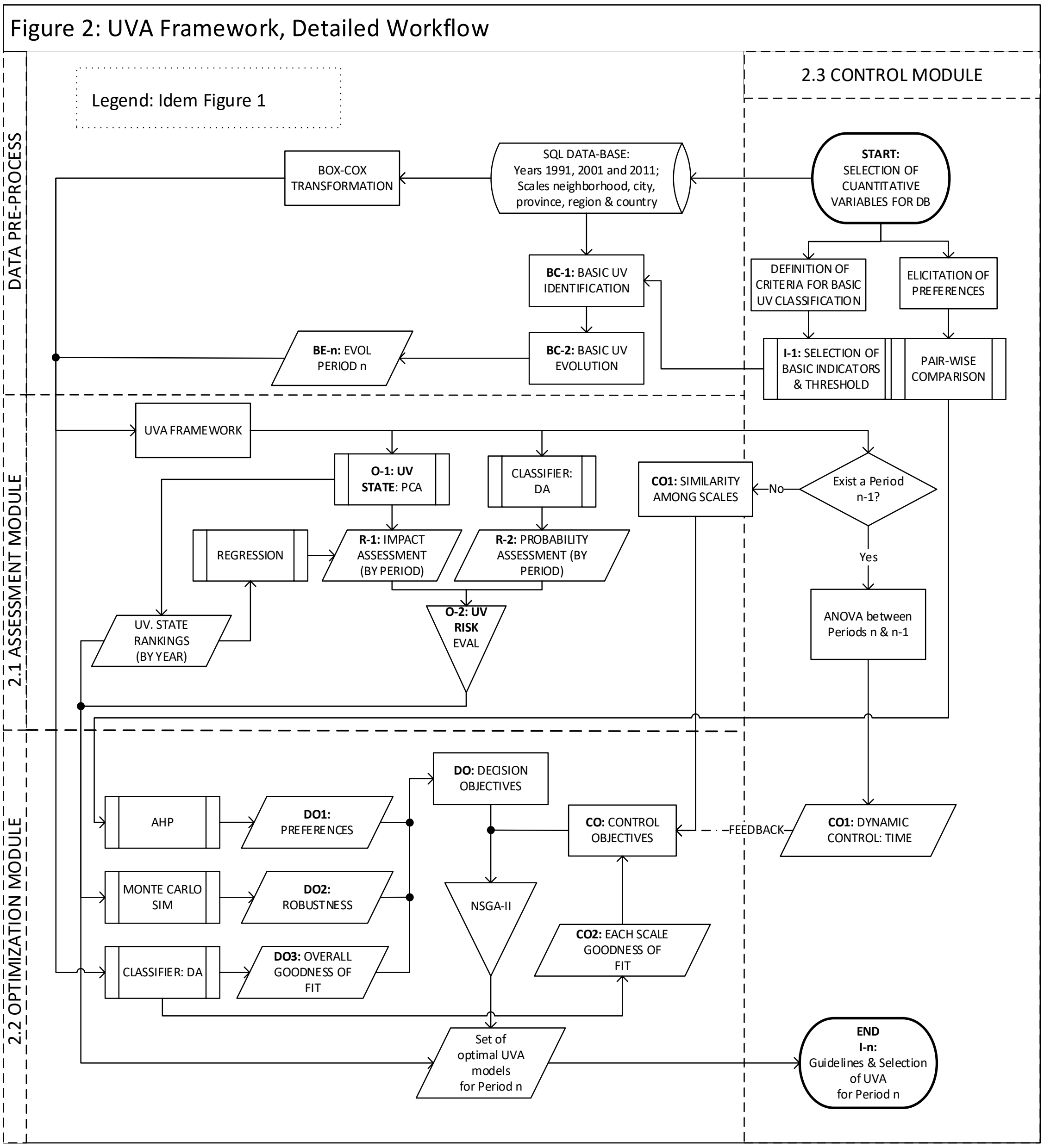

Figure 3.2: UVA Framework, Detailed Workflow

Objectives	Functions: f obj	Functions: Eq	Period 1: Best by objective (minimize)* A	Period 1: Best by objective (minimize)* B	Period 1: A/B	Period 2: Best by objective(minimize)* A	Period 2: Best by objective(minimize)* B	Period 2: A/B
Decision Objectives:								
Preferences	1	1	-0,953	-0,95	1,003	-0,957	-0,913	1,048
Robustness	2	2	-67.213	-79.776	0,843	-21.184	-21.405	0,990
GOF Overall	3	4	-2,243	-2,32	0,967	-1,696	-1,879	0,903
Control Objectives:								
Multi-Scale Simirarity	4	6	-0,048	-0,037	1,297	-0,108	-0,065	1,671

Time Dynamics	4	5		-2,989	-2,989	1,000
GOF scale 1: Neighborhood	5	3	-0,08			
GOF scale 2: City	6	3	-0,25		-0,303	
GOF scale 3: Province	7	3	-1		-0,674	
GOF scale 4: Region	8	3	-1		-1,000	

A: GOF represented by 1 overall objective

B: GOF represented by 1 overall objective and independient objectives by scale

(*) Compriomise solutions after 500 iterations and a population of 300 individuals

Table 3.1 Objectives describing behaviour and comparative between optimizations with and without breaking down the GOF objective

This resulted in the formulation of a many-objective optimization problem (MOOP) aiming to find the best compromise solutions for the designed characterization framework. For this purpose, the aforementioned qualities of robustness, GOF and preferences of DMs were introduced as decision objectives in the MOOP (Figure 3.2, DO). The objectives should not only demonstrate the model's behaviour but also provide them with the required supervision. This supervision must ensure proper guidance of the process of searching for solutions and eventually achieve the compliance with the minimum conditions where required. This can be settled by aggregating the control objectives into the MOOP itself and by introducing constraints in the form of penalty functions (Zhou et al., 2011). Control objectives (Figure 3.2, CO) handling issues regarding both the multi-scale and the dynamic nature of urban vulnerability were therefore incorporated in the MOOP. In addition, penalty functions were introduced in the UVA. These constraints make eventual violations of the conditions evident to the statistical techniques employed across the whole process by penalizing the value of the solution in the objectives, allowing the DM to decide whether to discard them.

In this way, embodying the already stated requirements into the process entailed the development of the following objectives:

Definition of decision objectives (DO):
Decision objectives describe the behaviour of a set of solutions (Fig. 3.2) and offer criteria for selecting one of them:

Subjective preferences (DO1):
This objective was evaluated as the sum, over the set of indicators shaping the model, of the weights derived for each variable/indicator:

$$P = \sum_{k=1}^{n} w_k \qquad (2.0.1)$$

In order to evaluate the degree to which indicators of any UVA model are preferred by practitioners, the preferences of these latter should be previously modelled. Analytic Hierarchy Process (AHP) is a systematic method comprising participatory processes

(Pellicer et al., 2016) that, with the aim of grasping the stakeholders preferences, has been commonly used in the field of strategic planning (Kubler et al., 2016; Penades-Pla, et al., 2016) for the aggregation of qualitative information concerning social sustainability (Zamarrón-Mieza et al., 2017). Specifically, AHP has proved to be effective for urban management when planning the participation of citizens by recognizing their values (Hong & Chung, 2016), as well as for grasping preferences for indicators (Khalil et al., 2016) (our case). Furthermore, AHP can be integrated within many-objective optimization processes (Leong et al., 2017; Yepes et al., 2015). Therefore, we adopted this method for modelling the preferences of practitioners (DMs) for indicators, and integrating them within the MOOP process.

For this purpose, a questionnaire was developed in which the indicators were structured into a hierarchy of 3 levels: goals, vulnerability approaches, vulnerability aspects and vulnerability indicators (Table 3.2). This hierarchy basically followed the well-established qualitative analysis of the selected indicators made by Alguacil et al. (2014). For the administration of the survey, a letter of invitation and the questionnaire were distributed to experts (Khalil et al., 2016). The respondents were asked to assess, via pair-wise comparison of elements within the same hierarchical level, how much each element was preferred over the others, as a useful indicator for evaluating urban vulnerability in an area. Therefore, biophysical aspects were pair-wise compared with the socio-economic aspects, which in turn were internally compared, and so on. This enabled identifying the relative importance, in terms of weights of variables, given by the involved practitioners (DMs) to all the assessed concepts.

Concepts	Id	Precedent	AHP Relative Importance	Period 2: Indicators setting up				
				Robust (**)	GOF (**)			Preferen (**)
				2	2	3	4	2
Approaches:								
Socio-Economic	SEA	-	51,81					
Biophysical	BA	-	48,19					
Aspects:								
Social structure	SSTR		27,68					
Population Activity level	PACT	SEA	11,49					
Population Educational level	PEDU		12,64					
Area occupation	AOCC		9,6					
Dwellings condition	DCON		11,75					
Dwellings size	DSIZ	BA	16,37					
Dwellings usage	DUSA		5,63					
Dwellings age	DAGE		4,84					
Indicators:								
Area Population	1		3,64	0	1	1	1	1
Population density (pop/ha)	2		8,84	1	1	1	1	1
Eder 75 years or more (%)	3	SSTR	5,85	1	1	1	0	1
Households of one person older	4		3,68	0	1	0	1	1
Households of one adult and at	5		5,67	1	1	1	1	1

(*) BI-1: Unemployment rate	6		4,47	1	1	1 1	1
Youth unemployment rate (%)	7	PACT	1,99	1	1	1 1	1
Tempory employee (%)	8		2,02	0	1	0 0	1
Unqualified workers (%)	9		3	1	1	1 1	1
(*) NI-2. Population uneducated	10		4,24	1	1	1 0	1
Population with primary	11	PEDU	3,8	0	1	1 1	1
Population with secondary	12		1,75	1	1	0 1	1
Population with higher education	13		2,85	0	1	1 1	1
Number of dwellings(u)	14		1,65	1	1	1 0	1
Dwellings density (u/Ha)	15	AOCC	6,15	0	1	1 1	1
Area (Ha)	16		1,8	1	1	1 1	1
(*) BI-3: Dwellings rate (%	17		1,05	1	1	1 1	1
Dwellings in ruin condition (%)	18		3,4	0	0	1 1	1
Dwellings in bad condition (%)	19	DCON	2,6	0	1	0 0	1
Dwellings in deficient condition	20		1,77	1	1	0 0	1
Dwellings in good condition (%)	21		1,29	0	1	1 1	1
Dwellings without running water	22		1,64	1	1	1 1	1
Dwellings with less than 30 m2	23		2,75	0	1	0 0	1
Dwellings total usable surface	24		2,5	0	0	0 0	0
Mean usable surface by dwelling	25	DSIZ	3,88	0	0	0 1	0
Mean usable surface by habitant	26		3,44	0	1	1 1	1
Number of rooms by dwelling	27		3,8	1	1	1 1	1
Main Dwellings (u)	28		1,05	1	1	1 1	1
Empty Dwellings (u)	29	DUSA	2,34	1	1	1 1	1
Owned Dwellings (u)	30		0,76	0	1	1 0	1
Rented Dwellings (u)	31		1,48	0	1	1 1	1
Dwellings in buildgs built before	32		1,49	1	0	0 0	1
Total buldings (u)	33		0,44	1	0	1 1	1
Buildings older than 30 years (u)	34	DAGE	0,51	0	1	1 1	1
Buildings older than 50 years (u)	35		1,45	1	1	1 1	1
Buildings older than 80 years (u)	36		0,96	0	1	0 0	0

(*) Criteria selected for the basic classification starting up the UVA framework
(**) Scales: 2 = City; 3 = Province; 4 = Region.

Table 3.2 Results of the AHP process and of the best model for each decision objective.

Robustness (DO2):

Uncertainty analysis conducted via the Monte Carlo simulation method is recognized as an appropriate method for assessing the robustness of index-based rankings (Marozzi, 2016; Hermeling et al., 2013), which is the case here. Broadly speaking, this method analyses how a model's outcome behaves when the inputs vary within an expected range of values. Having performed the Monte Carlo simulation, the robustness of the model can be evaluated by assessing, for each k input variable, the relative size of its variance v with respect to its mean m, and then aggregating these ratios, obtained for the n variables composing the model, to assess its overall robustness R:

$$R = 1 \Big/ \left(\sum_{k=1}^{n} \left(\frac{v_k}{m_k} \right) \right) \tag{2.0.2}$$

Models with small variance in comparison with the mean are robust (Hermeling et al., 2013). This method adds sensitivity to the uncertainty analysis, thereby enhancing the information thus obtained. Therefore, we selected this approach for our method. This objective was stated as

Goodness of fit (DO3). The goodness of fit (GOF) is crucial when treating both the accuracy and validity of a model. This has been commonly tackled by analysing the model's output error in general (Boada et al., 2016). The use of the Normalized Root Mean Square Error (NRMSE) as a criterion to select the most appropriate model in the case of the existence of extreme values in the data-set has been successful in the development of UVA methods (Karagiorgos et al., 2016; Akumaga et al., 2017). We therefore formulated the GOF objective, for each scl scale, as follows:

$$GOF_{scl} = \sqrt{\frac{\sum_{i=1}^{p}(S_i - O_i)^2}{p} \times 100/\bar{O}} \qquad (2.0.3)$$

where the index i runs over p number of observations, and S_i, O_i and $\bar{O}$ respectively represent the value predicted by the model, the value observed and mean of the values observed.

In consequence, the overall GOF is formulated as the sum of all the GOF by scales:

$$GOF = \sum_{scl=1}^{nscales} GOF_{scl} \qquad (2.0.4)$$

where $nscales$ is the number of political-administrative scales considered.

Definition of control objectives (CO):

Control objectives are the objectives that contribute to guiding the search process and identifying the solutions with the above mentioned attributes that are demanded for UVA, despite their not being relevant in the selection of the characterization model.

Both resilience and vulnerability are complex, context-dependent concepts that dynamically change over time and space. The latter refers not only to the physical position of the analysed systems but also to the socio-political scale by which it is affected (Fuchs & Glade, 2016; Herslund et al., 2016). The proposed UVA framework addresses this feature by comparing the evolution of systems along time and political-administrative scales. Therefore, some control is required in linking the different moments and scales considered in the analysis. For this purpose, two classes of control objectives additional to the basic classes were employed.

The first class provided a criterion through which the different intervals constituting the overall time span are connected, and was evaluated in terms of the higher p-value resulting from the ANOVA test (Mzolo et al., 2015):

$$H_{0,k} = \mu(t_{k-1}) = \mu(t_k) \qquad (2.0.5)$$

Where k and t are, respectively, the interval analyzed and the instant of time that is both the end point of the k period and the prediction projected, for that instant, by the risk assessment produced at the $k - 1$ period. That relation enabled us to connect the time slices by looking for models that behave alike, which we implemented through the maximization of those p-values as the first of the control objectives (Figure 3.2, CO1).

The second class, on the other hand, gathers a series of objectives, which afforded models with the best fitting for each scale, and therefore made more explicit the effects that between them might be conveyed to hierarchically-dependent systems. This was implemented by setting up as many objectives as scales, maximizing the GOF corresponding to each scale (Figure 3.2, CO2). For the sake of simplicity, we looked after some heterogeneity in the variables selected across the scales by introducing a criterion of similarity among them. This was evaluated through the Euclidean model, whose distances were transformed into similarity as the inverse of the modified exponential decay (Jo et al., 1997):

$$S_{ab} = e^{-d_{ab}}, \forall\, d_{ab} \qquad (2.0.6)$$

Where S_{sb} is the similarity between cases a and b, and d_{ab} is the Euclidean distance between these cases.

The increase in the number of objectives arising from having to consider those dynamic aspects impelled us to a many-objective configuration of the problem, which is considered an appropriate method for dealing with real-world, complex problems (Zhou et al., 2011). Table 3.1 portrays all the objectives considered in the many-objective configuration (column B), which can be formulated as:

$$minimize\ F\ (x) = \left(f_1(x),\ldots, f_{obj}(x)\right)T \quad s.t. x\ \in\ \Omega, \qquad (2.0.7)$$

where Ω is the decision space, $x \in \Omega$ is a decision vector and obj is the objective function accordingly to Table 3.1.

3.2.4. UVA Assessment Module (Figure 2, 2.1)

Data Pre-processing

As mentioned in the general workflow section, the process begins with the interaction 1 (Figure 3.1, I-1), in which basic indicators and thresholds are decided. This interaction allows performing a basic identification of entities as vulnerable and non-vulnerable in a given time, depending on whether thresholds are exceeded or not (Figure 3.2, BC-1). This classification was carried out for the first and last years of each period considered, allowing the statement of a basic UV evolution classification (Figure 3.2, BC-2) into three categories, according to whether entities changed from non-vulnerable to vulnerable, or vice-versa, or experienced no change. The result of this classification (Figure 3.2, BE-n) was aggregated as a dynamic variable always present in the analysed data set, and used as a reference to supervise the searching of the proper set of indicators in the Optimization

Module (Figure 3.2, DO3).

Ranking of UV State (Figure 3.2, O-1)**:**
PCA is a statistical technique based on the analysis of variance that has previously been used to both assess the relative importance of socio-economic and physical indicators (Shen et al., 2012) and to build resilience rankings (Kotzee & Reyers, 2016). Further, PCA relies on variation and covariation of the data and produces factors accounting for the variance of the data set. A set of factors explaining at least 85% of the variance of data is regarded an adequate model. On this basis, a comprehensive assessment model can be developed by going through the following four step process (Shen et al., 2012):

1. Selection of a set of factors accounting for more than 85% of total variance.
2. Transformation of principal components into a relation between a correlation coefficient in the factor loading matrix ($r_{x_i PC_j}$) and the coefficient vector of each principal component (denoted by a_{ij}). That relation is given by Equation (8), with λ_{pc} being the eigenvalue of the pc^{th} principal component factor.

$$r_{x_i PC_j} = \sqrt{\lambda_{npc} a_{ij}} \quad (2.8)$$

3. Using this method, as many equations as principal components are obtained, allowing us to calculate a general equation using which the weight of each variable can be derived. This can be obtained by normalizing each eigenvalue to the sum of eigenvalues of the whole set of components (Lin & Zhang, 2005; Zhang, 2006), as shown:

$$SV = \sum \left(\frac{\lambda \text{npc}}{\lambda 1 + \lambda 2 + \cdots + \lambda \text{tpc}} \right) PCnpc \quad (2.9)$$

4. The last equation provides normalized values of each λi for each principal component PC_i, that is to say, for each one of the equations obtained in in step (ii), and therefore allows directly relating the data variables through their weights calculated in step (iii), with the comprehensive assessment model outcome, SV. We can now pass each observation though the assessment model to obtain a corresponding Vulnerability State value, which will be the criterion used for its ranking (Figure 2, O-1).

Risk and opportunity (Figure 3.2, O-2)**:**
For each entity, the risk of becoming more vulnerable, i.e. of losing positions in the vulnerability state ranking, was obtained as a result of the product of the probability of becoming more vulnerable and the impact on the ranking previously derived (Villa et al., 2016; Dai et al., 2002; Kaplan& Garrick, 1981; Brooks, 2003).

- **Risk Evaluation: Impact Component** (Figure 3.2, R-1)**.** For each scale, entities were ranked accordingly to their UV state. The assessment of the impact for each period relates its evolution, in terms of positions gained or lost in this ranking, with that of the indicators shaping the model. Using variance as a measure of impact has been previously attempted in the field of risk assessment (Osanloo & Rahmanpour, 2017; Parvizimosaed et al., 2017; Mi et al., 2017).

For the formulation of impact, multiple linear regression was performed using the data set variation from the starting to the finishing year of the period considered as predictors and the UV state rank variation, i.e. number of positions gained or lost, as the response. A minimum value of 0.3 for R^2 parameter and a maximum value of 0.05 for the *p*-value were granted by setting these conditions as constraints via a penalty function (Zhou et al., 2011), affecting the GOF objective in the optimization process. The coefficients thus obtained were used to assess the impact for each entity.

- **Risk Evaluation: Probability Component** (Figure 3.2, R-2)**.** Discriminant analysis has been widely used as a density estimation approach to tackle the probability estimation problem (Malley et al., 2012*;* Nielsen et al., 2016) and is therefore used for risk assessment purposes. This supervised technique aims to find the so-called discriminant functions, following the principle of maximizing the difference between two classes while minimizing that among members of the same group. In addition, for each observation (entity), the posterior probability of belonging to each class is given.

The model uses DA to assess the possibility of falling within each one of the three possible classes for all observations. These classes refer to the type of evolution experienced by each observation through the period of time considered: negative, stable or positive, when observations exhibited a vulnerable, indifferent or resilient behaviour, respectively, in terms of the basic classifications elicited in the data pre-processing stage (Figure 3.2, BE-1 to 2). As a result, DA was performed by considering the evolution of variables as predictors and that of the basic classification as responses, thus obtaining the probabilities required for the risk assessment.

3.3 Case study

3.3.1. Assessment of Urban Vulnerability in Spain

We considered the presented UVA method's application for assessing the UV in Spain. Following the three-step process mentioned above, the objective is to provide DMs with the guidelines required for the selection of a proper UVA model. Spain is a country concerned with UV to the point of having invested, from 1999 to 2013, up to 1.103.107.807 € through the URBAN I, URBAN II, and Iniciativas Urbanas-FEDER European programs, which were designed to face urban vulnerability. Based on the work of Gómez et al. (2014), this country has developed an Observatory of Urban Vulnerability (OUV) that plays a key role in the development of strategies involving housing, transportation and infrastructure investments (Infrastructure, transportation and housing plan-PITV 2012-2020, Spanish Ministry of Public Works). Using the data obtained from the population and housing censuses of 1991, 2001 and 2011 of the Spanish National Institute of Statistics (INE), this observatory provides an assessment of vulnerability levels on a neighbourhood scale for cities of the country with more than 100,000 inhabitants or the capital of the province (OUV). Also, they have put the data for 1991 and 2001 that were used for the assessment at the disposition of the public. As the first step of our process, we retrieved the data of those years. In order to extend the assessment, we added the data corresponding to the scales of city, province and autonomous community (INE), and also added more variables, regarding the built environment, that were available (Table 3.2). In synthesis, for the years 1991, 2001 and 2011, data corresponding to 36 indicators for up to 142 cities, 52 provinces and 19 regions (17 autonomous communities plus Ceuta and Melilla) were collected. For the suburbs, of the 687 neighbourhoods identified, only material corresponding to the years 1991 and 2001 was used, since that of 2011 was unavailable.

3.3.2. Collection and pre-treatment of data and expert-judgment

All this information was assembled in an SQL database, which in turn was linked to the Matlab® code automating the whole process described in the methodology section, including the UV assessment framework (2.4), the optimization (2.3) and control (2.2) modules. Since the statistical techniques used in the UVA required a normal distribution in the input, a Box–Cox transformation was applied (Box & Cox, 1964). At the same time, based on the AHP method described above, a survey was conducted of experts in urban planning, resulting in 10 answers in which consistency was tested (Saaty, 1990). According to Saaty and Özdemir (2014), AHP does not require a pre-determined number of surveys for granting its validity. During the data entry, the consistency of the responses was evaluated and improved if possible without altering priorities in judgments (Singh & Nachtnebel, 2016). Of the 10 responses, only 9 were accepted for further analysis. Then, the overall preference of each UVA practitioner was elicited as the non-normalized geometric mean of all individual preferences, and the results are shown in Table 3.2.

3.3.3. Set-up of the process

As with the basic classification of vulnerability, we accepted the standard adopted by OUV of setting up a threshold for a set of basic indicators. Those basic indicators were the proportion of unemployed population, proportion of population without studies, and the proportion of dwellings, or of people living in dwellings without bathroom or toilet (OUV). As a result, the model regarded as vulnerable those entities falling 1.5 times further than a given reference. As this reference, the OUV considered values at the country scale and compared with it all neighbourhoods in the country regardless of the city, province and region containing, and therefore contextualizing, them. Since UV is context dependent (Fuchs & Glade, 2016; Herslund et al., 2016), instead of the absolute approach employed by the OUV we applied a relative one in which entities were referred to that entity of the upper scale containing them.

As the second step, we conducted the dynamic process associated with the control and optimization modules described in the methodology section. Based on the methodology reported, the model was formulated as a nine-objective optimization problem (Table 3.1) with binary variables, i.e. the values the variables can take are 1 or 0 depending on whether they exist or not in each characterization model. For the robustness objective, we followed the process described in the methodology section, producing 100 random outcomes for each candidate via the Monte Carlo simulation method. Since we had several scales, the decision objectives were expressed as the sum of the results corresponding to each scale, except for the case of subjective preference, expressed as the mean of the values. The program was coded in Matlab® with an INTEL® CoreTM i7-4712 CPU processor at 2.3 GHz. Starting from an initial random population of 300 individuals, 500 iterations (a number of iterations that has been found acceptable for the case of multi-objective optimization of binary-real coded variables (Abdul-Rahman et al., 2013) were set as the maximum number of generations to be obtained (Alajmi & Wright, 2014). Crossover and mutation probabilities were set to 0.6 and 0.5, respectively.

3.3.4. Run of the process

We thus obtained a set of Pareto-optimal UVA models corresponding to the first period, i.e. 1991–2001, which we analysed in order to obtain the guidelines of their behaviour. As expected, these solutions show a trade-off between the criteria used for its assessment. With this knowledge, a model was selected and the UVA framework was applied for period 2 (2001–2011). Again, a set of optimal UVA models was obtained. This time, however, during the optimization process a dynamic control for time was added to the set of previous objectives, which served as criteria for the evaluation of alternatives (Table 3.1). This additional objective enabled DMs to select among those UVA models of the second period better connected with that of the first period providing the feedback. As a result of that latter, a desired behaviour was identified and the corresponding selected UVA model was realized, which enabled ranking the neighbourhoods, cities, provinces and regions assessed from less to more vulnerable.

To test the performance of the breaking down of the overall GOF objective into as many factors as there are scales, a comparison was made between the results obtained in both cases, and the results are presented and discussed at the end of the next section.

3.4 Results and Discussion

3.4.1. Guidelines for Period 1, 1991-2001

The above mentioned process was used to yield results for periods 1 and 2. In the first period, i.e. 1991–2001, a set of Pareto-optimal solutions, represented in Figure 3.3, was obtained. To improve the extraction of knowledge from the results, we furthered the analysis by using a cognitive approach entailing a comparison of the best solutions for each decision objective (Table 3.2).

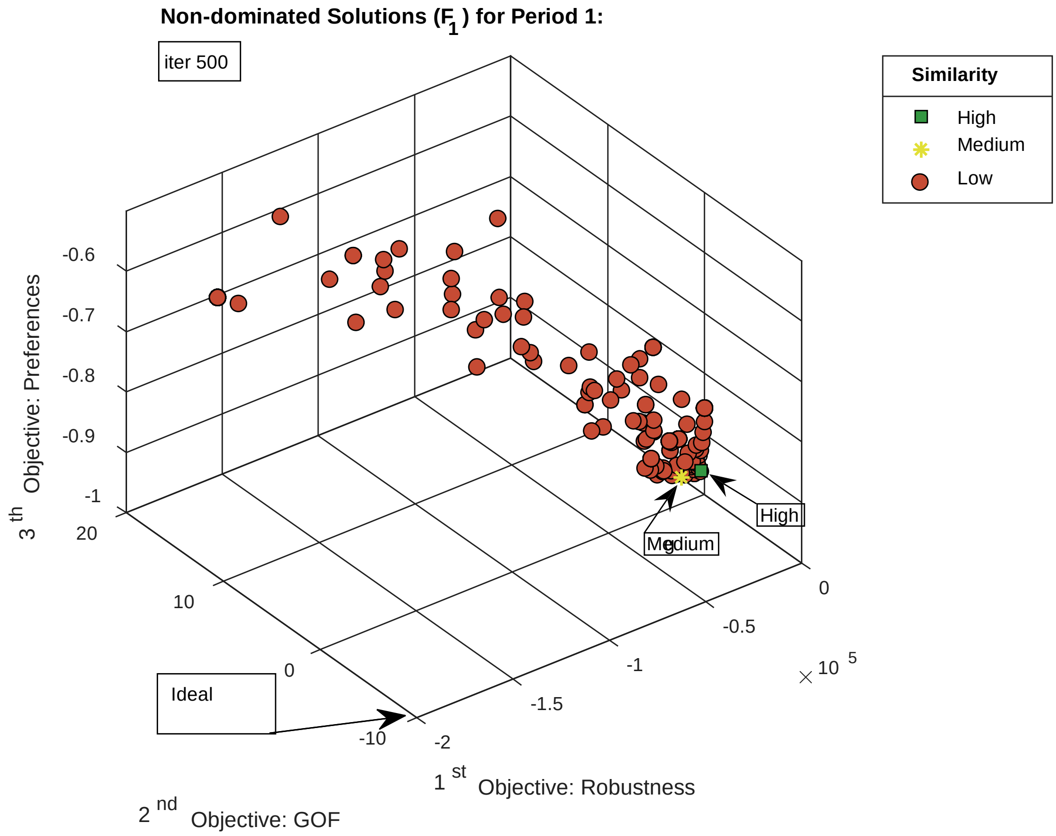

Figure 3.3 Set of compromise solutions for period 1.

The interpretation of these results provides guidelines regarding the trade-offs between the decision objectives just mentioned. This enables us to draw conclusions on the behaviour of models in terms of their robustness, coincidence with expert's preferences, and their GOF. In addition, with the knowledge thus acquired, DMs are in a better position to define the desired behaviour to subsequently select, directly from the Pareto front, a UVA model that gives way to the evaluation of period 2.

Figure 3.4 portrays the trade-off between the robustness and GOF objectives. Solutions performing well in terms of robustness are poor in terms of GOF and vice versa, showing that these two objectives are contradictory. In addition, we implemented a semi-automated alternative for enhancing the extraction of guidelines (Boada et al., 2016). The solutions gathered were clustered according to their performance and the similarity-among-scales control objective.

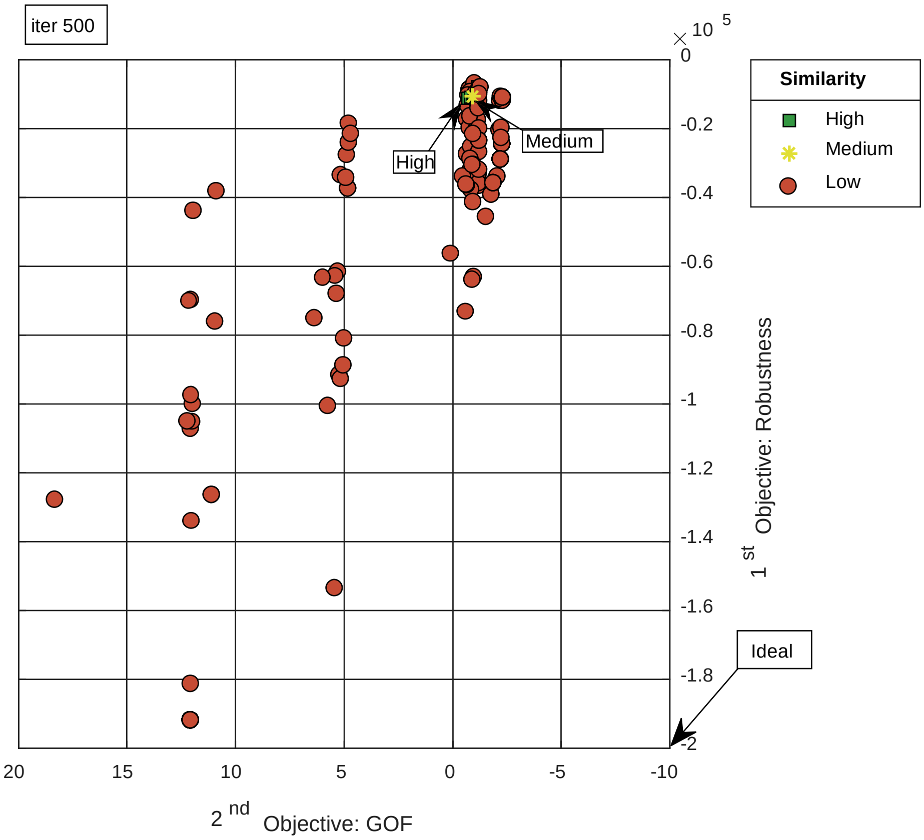

Figure 3.4 Trade-off between Robustness and GOF for period 1.

Solutions with low similarity, marked with asterisk, are spread throughout the space, while those with higher similarity, marked with squares, were concentrated close to the best solution for the GOF criterion. The solutions with higher similarity, in turn, are also directly related with those performing better for the preferences objective (Figure 3.5) and inversely related with the robustness criterion (Figure 3.5). As a result, for the first period the following guidelines were elicited (Figure 3.2, I-1):

- Models with more robust behaviour are less related to practitioner's preferences and have less accuracy. In addition, in such models, the similarity between the set of indicators across political-administrative scales is low.
- Preferences of practitioners, GOF and similarity between scales are aligned with each other.

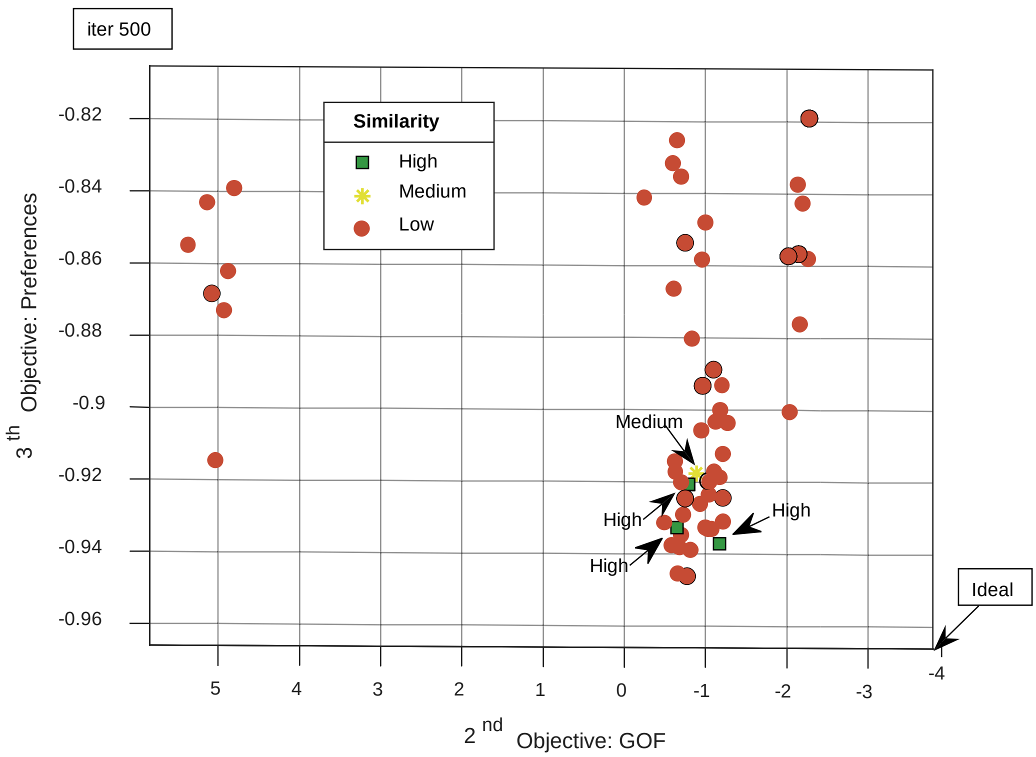

Figure 3.5 Trade-off between GOF and preferences for period 1

3.4.2. Guidelines for Period 2, 2001-2011

With the knowledge thus obtained, we decided to choose, as the reference for the time dynamic-control objective of the second period, the most robust model among the models fitting the guideline above.

The results for the second step are presented in Figure 3.6. The analysis of these results allows extracting, as in the previous case, the guidelines for identifying a desired behaviour. For period 2, solutions were clustered according to the time-dynamics control objective instead of the similarity across scales. The time-dynamics criterion's performance is slightly and directly related with that of GOF and strongly and inversely related with those of robustness and preferences which, in turn, also exhibit an inverse relation among themselves.

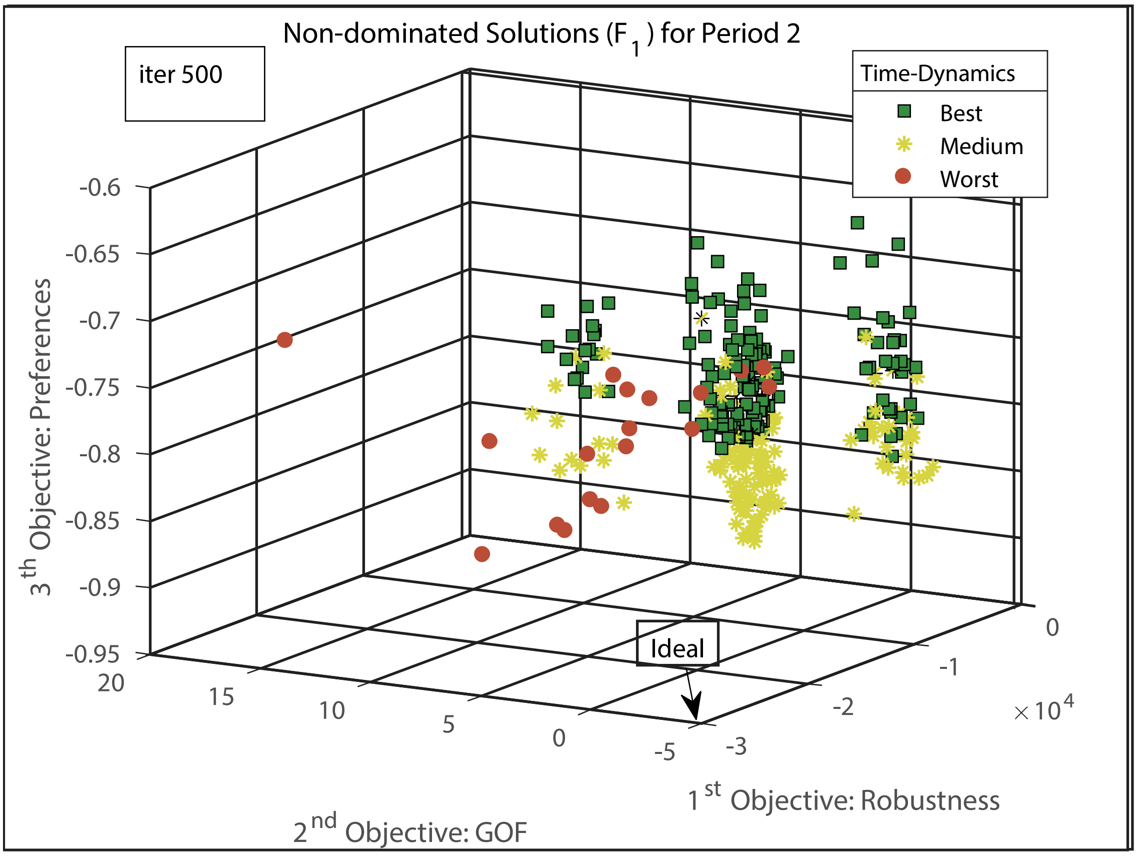

Figure 3.6 Compromise solutions for period 2.

Regarding the GOF objective, Figure 3.6 shows that the solutions most preferred by practitioners have not overcome the 0 value in the GOF scale, which means that the threshold, required for *p*-value and R^2 values of the impact assessment, was not reached in any of the scales, penalizing the GOF. Besides, the inverse relation which for the case of GOF and robustness was noticeable in period 1 is also present in period 2. Models preforming better in terms of the time-dynamics objective are present throughout the space of compromise solutions. However, they are clearly concentrated in the proximity of solutions better for the GOF but worse for the preference objectives (Figure 3.6).

On this basis, the following guidelines can be drawn for period 2 (Figure 3.2, I-2):

- The most preferred solutions are not the best dynamically connected over time and do not fulfil the statistical conditions required by the UVA framework. The DM should decide whether they wish to relax those requirements.
- The inverse relations identified in period 1 between the preferences and GOF objectives and the robustness objective are still present in period 2. This, together with the fact that the time-dynamics criterion is akin to that of the GOF, affords a range of solutions behaving well in terms of the GOF and time-dynamics, yet medium to poor for preferences and robustness criteria, respectively.

3.4.3. Improvements rendered by the many-objective approach

Table 3.2 portrays how the set of variables selected as indicators changes across scales for better representing the UV. The use of a many-objective approach has proven efficient for the sake of attaining the best overall GOF by pursuing the best GOF scores by each scale, allowing UVA to consider the complex character of this concept. Table 3.2 also depicts the equality in the share of importance bestowed upon biophysical and socio-economic aspects, suggesting the preference of practitioners for comprehensive approaches considering both standpoints. This is consistent with the conclusions of previous publications in the literature, considering the comprehensive approach as a requirement for attaining more-evolved UVAs.

Regarding the employment of the many-objectives approach for dealing with the multi-scale character exposited in the control objectives section, Table 3.1 portrays a comparison between the results obtained by using this approach with those from a single overall GOF objective. The results show that for all periods, the addition of GOF objectives by scale contributes to improve the results in the overall GOF. This leads, however, to slightly worse results for the preferences and multi-scale objectives in the case of period 1, and for that of robustness in period 2.

As to the optimization algorithm employed, NSGA-II modified the selection operators of the original NSGA. Via this approach, the lack-of-elitism problem was alleviated but not completely overcome. In fact, the state-of-the-art of evolutive optimization algorithms suggests that the most widely used selection operators still do not work well when dealing with more than three objectives, i.e. with many-objective problems (Zhou et al., 2011), an idea which the present paper seems to support. Our results demonstrate the difficulties this algorithm has to avoid the loss of performance in some objectives, when their number of these objectives increases.

3.4.4. Improvements regarding the current UVA in Spain

On the other hand, the share of importance conferred by practitioners on the indicators available to assess urban vulnerability greatly varies from one indicator to another. Table 3.2 shows how this relative importance varies from the most to the least preferred indicators, pointing out Population density, Dwellings density and Elder 75 years or more, as the most important for the experts consulted. In contrast with the assessment adopted by the Spanish Government, the method hence proposed embodies this information and allows selecting UVA models shaped by those indicators considered more relevant by practitioners for the assessment of both the Vulnerability State and Risk. As well, a comprehensive assessment of the whole country, across its different political-administrative scales, of entities contextualized within their environment, is provided. With this information, DMs can identify both current states of vulnerability and trends for the future, and extend the evaluation of entities beyond the current mere classification into vulnerable or non-vulnerable. Further, it allows a deeper and wider analysis of the UV problem, and the design of more complete and better adapted strategies. For example, entities still at the first stages of degradation but yet at high risk, which would be considered as a prior target, can now be identified, and plans can accordingly be made.

Through the employed cognitive approach, DMs are now enabled to select, according to the knowledge acquired, a proper solution from among the set of compromise solutions yielded by the optimization module (Figure 3.2, 2.2). This mechanism serves, in fact, as the scenario generator required for developing bottom-up uncertainty analysis methods (Hall et al., 2012). For period 2, 80 compromise solutions fulfilling the statistical requirements were found, with values ranging from 2,002.35 to 8,217.39 in the case of the Robustness objective, from 1.09 to 1.85 in the case of GOF, and from 0.46 to 0.86 in that of Preferences.

3.5 Conclusions and further research

In pursuit of sustainable urban development, the improvement of UVA methods is a key issue that has attracted the attention of many governments (Fekete, 2009; Rigillo & Cervelli, 2014; Malekpour et al., 2015). This improvement can be realized by developing models integrating the features demanded in this field. This paper puts forward a method integrating the aforementioned requirements that can be used to determine the optimum set of indicators which, for the proposed UVA assessment model, follow a desired behaviour. This behaviour is modelled in terms of robustness, GOF and preferences of practitioners, and the overall process is formulated as an MOOP. Moreover, a set of underlying control objectives provided insights on the dynamic character of UV over time and context.

The proposed method uses a discursive approach in which DMs and the model interact and give each other the required support, which affords DMs with more knowledge on the dynamic interactions between criteria. This enables them to make an informed, evidence-based decision on the issue at stake. First, this study introduced the aspects required for UVA and proposed the formulation of a process encompassing all requirements, as an MOOP to be solved by the NSGA-II algorithm. Then, the whole process was described and tested via a case study. For this purpose, Spain has been used as an example, and quantitative data on the neighbourhood, city, province, region and country political-administrative scales was gathered. In addition, qualitative information in terms of the preferences of practitioners for the indicators available was elicited, showing great differences from one practitioner to another. With this information, the process was performed, and the results showed that the method is endowed with the qualities demanded and is able to draw out general guidelines of the model's behaviour. Finally, the guidelines suggest that for the proposed UVA assessment model it is possible to select models better dynamically connected over time and fitting well in terms of GOF, at the expense of a medium or bad performance in preferences and robustness.

As to the Urban Vulnerability Assessment module, the method proposed provides UVAs which involve practitioners by taking into account their subjective preferences, are robust in the face of data uncertainty, and are statistically derived through commonly accepted techniques. Since there are UVA methods making use of these features separately, the novelty of this work consists in their integration to take advantage of the benefits of their synergies. Besides, the process provides a UV State and Risk Assessment according to the requirements demanded, enabling planners to carry out an improved analysis of the UV problem in Spain in order to develop better adapted strategies.

All this together means moving on the assessment of Urban Vulnerability in Spain, from the earlier stages of development in urban strategic planning and vulnerability assessment, to the discursive and adaptive governance stages characterizing present trends in these fields (Malepour et al., 2015; Fussell et al., 2006). At the same time, the method proposed helps bridge the gap as to the development of the demanded improvements in adaptive governance and strategic planning in the context of climate change and socio-economic transformation.

As to modelling of the multi-scale nature of urban vulnerability, our study shows how to use many-objectives approaches to tackle this problem, improving the outcome of the optimization in the objective affected.

Despite the remarkable outcomes, there are still limitations to this study. More research is required on the selection of the basic criteria upon which the whole process rests, exploring different indicators, thresholds and references. Also, the use of other machine-learning methods such as neural networks, SVM or Naïve Bayes networks, can be tested to obtain more accurate models. In addition, this methodology embodies a basic dynamic control over time and context that should be improved in future research focusing on this issue. Regarding this latter, research on the spatial correlation among entities could disclose valuable information with which to improve the assessment module. Finally, in addition to the abovementioned limitations, two more can be pointed out for the case study. First, the number of expert-judgment collected for the elicitation of preferences was relatively low, suggesting a broader survey in order to obtain more representative values. Second, the output of the process was a rather large set of optimum solutions, among which DMs must choose one with the aid of the guidelines provided. The implementation of dimension-reduction techniques, such as cluster analysis, would facilitate the decision making by synthesizing the set of optimum solutions into a smaller, affordable number of representative ones.

List of Abbreviations:

UVA: Urban Vulnerability Assessment
UV: Urban Vulnerability
USP: Urban Strategic Planning
DM: Decision Maker
GOF: Goodnes Of Fit
RMSE: Rooth Mean Square Error
NRMSE: Normalized Rooth Mean Square Error
AHP: Analytic Hierarchy Process
MOOP: Multi Objective Optimization Problem
DA: Discriminant Analysis

PCA: Principal Componentes Analysis
NSGA-II: Non-dominated Sorting Genetic Algorithm
SVM: Support Vector Machine

List of Notations:

P	Preferences
w_k	Weight of the k indicator
n	Total number of indicators
R	Robustness
v	Variance of the set of monte carlo simulations
m	Mean of the set of monte carlo simulations
$GOF_{scl} =$	Goodness of Fit for the scale number scl
i	Number of each observation
p	Total number of observations
S	Value predicted
O	Value observed
$\bar{O}$	Mean of the values observed
$nscales$	Total number of scales
$H_{0,k}$	Null hypothesis for the ANOVA test of equal means for the k period
μ	Means at the t instant
S_{ab}	Similarity between a and b
e	Number e
d_{ab}	Euclidean distance between a and b
F	Function of the f continuous objective functions
obj	Total number of objective functions
x	Decision vector
Ω	Decision space
T	Set of Pareto-optimal solutions
$r_{x_i PC_j}$	Factor loading matrix
tpc	Total number of principal components
npc	Number of the principal component
PC	Principal component vector
a_{ij}	Coefficient vector of each principal component
λ	Eigenvalue of each principal component
SV	State of Vulnerability

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Capítulo 4

Process of selecting an Urban Vulnerability Assessment Model - Proceso de selección de un Modelo de Evaluación de Vulnerabilidad Urbana

Artículo 3: VisualUVAM: a decision tool addressing the curse of dimensionality for the selection of urban vulnerability assessment models.

Autores: Jorge Salas; Víctor Yepes

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Abstract

Many-objective optimisation methods have proven successful in the integration of research attributes demanded for urban vulnerability assessment models. However, these techniques suffer from the curse of the dimensionality problem, producing an excessive burden in the decision-making process by compelling decision makers to select alternatives among a large number of candidates. In other fields, this problem has been alleviated through cluster analysis, but there is still a lack in the application of such methods for urban vulnerability assessment purposes. This work addresses this gap by a novel combination of visual analytics and cluster analysis. Visual analytics allow for the delimitation of the space of compromise solutions yielded by the optimisation process and facilitates the extraction of knowledge by allowing both a bottom-up and a top-down analysis of the alternatives. Cluster analysis synthesises the space of solutions into a manageable number of representative alternatives. Based on an assessment framework previously developed, VisualUVAM is a decision tool that merges these techniques for the proposal, analysis and selection of an urban vulnerability assessment model for the province of Valencia, Spain.

Keywords: Visual analytics; Cluster analysis; Curse of dimensionality; Urban vulnerability assessment; Many-objective.

4.1 Introducción.

Urban vulnerability (UV) in general, and its adaptive component in particular, have become key issues for a sustainable urban developement (Fekete, 2009; Rigillo and Cervelli, 2014; Malekpour et al., Salas and Yepes, 2018b), which have lead, in recent decades, to the improvement of the existing urban vulnerability assessment models (UVAMs). In the pursuit of this, several research lines have been fostered, although with unequal intensity (Salas and Yepes, 2018a).

The abovementioned research lines are robustness as a way to cope with uncertainty (Dominguez et al., 2011; Hall et al., 2012; Malekpour et al., 2015), the use of cognitive approaches (Mustafa et al., 2011; Yepes et al., 2015; Pamungkas et al., 2014), a better understanding of UV dynamics over time and political-administrative scales (Adger, 2006; Birkmann et al., 2014; Liu el al., 2010; Pamungkas et al., 2014), and having a strategic, multi-objective capacity to avoid eventual tunnelling effects and to improve the adaptive capacity of the system (Munda, 2004). In addition, it is necessary to account for the subjective and complex nature of UV (Adger, 2006).

Previous works have reported the need to develop methods that integrate most of these research requirements in order to advance the field of UVAM towards the discursive stage in urban strategic planning (Romero Lankao and Qin, 2011; Salas and Yepes, 2018a). This stage represents the current trend in this field (Dominguez et al., 2011; Malekpour et al., 2015) and conveys the adaptive policy capacity demanded to face system vulnerability (Adger, 2006; Füssell and Klein, 2006). These methods, on the other hand, should also provide a quantitative assessment of risk, which integration with the other requirements can be achieved by means of multi-objective optimisation (MOO). This technique allows for modelling of the research requirements as objectives, such as the robustness of the model (as opposed to its sensitivity) or goodness of fit (Boada et al., 2016), so that these objectives work as the attributes demanded, which define the behaviour of the model.

Salas and Yepes (2018b) demonstrated the suitability of MOO for the attainment of the abovementioned integration, which provided a set of compromise solutions offering Pareto-optimal balances among the objectives. These objectives were seeking to maximise the subjective preferences expressed by practitioners, maximise the robustness of UVAMs, maximise their overall goodness-of-fit, maximise the similarity among indicators of different political-administrative scales and the dynamic connection over time, and maximise the goodness of fit at each scale. Simultaneously, this method allows for interaction between practitioners, decision makers (DMs) and the model, while providing trade-offs between objectives. From these trade-offs, guidelines can be elicited which, together with the participation of the DMs in the process, furnish the DMs with an improved knowledge of the problem at hand (Torres-Machi et al., 2017), enabling them to carry out an informed selection.

This selection, however, may be hindered by a dimensional problem with the number of available alternatives rendered by the process (Zio and Bazzo, 2011). To make the task feasible, only a small number of solutions, representative of the Pareto front, should be offered for selection to the DM. However, MOO processes typically yield a large amount of solutions (Ishibuchi et al., 2014) seeming a cloud of solutions (Santos et al., 2017) rather than a manageable set of them. This particularity more patently affects many-objective configurations (Ishibuchi et al., 2015), especially in the presence of conflicting or not aligned objectives, as in the case of selectin urban

UVAMs. The large amount of solutions, also called the “curse of dimensionality” by Kukkonen and Lampinen (2007), requires a specific treatment enabling DMs to focus their attention on those alternatives found relevant (Salas and Yepes, 2018b).

The employment of data analytics, such as cluster analysis (Kukkonen and Deb,2006, Zio and Bazzo, 2011, Taboada et al., 2007), or visual analytics, such as “brushing” solutions (Kasprzyk et al., 2013; Inselberg, 1997), have previously been used for alleviating the problem of unmanageable sets of alternatives. However, there is a lack of such approaches to reduce the dimension of solutions provided by UVAM selection decision frameworks.
This study presents a decision tool addressing this problem by extensive usage of visual analytics all along the decision process with the aim of selecting a proper UVAM for the assessment of UV in the province of Valencia, Spain. On the one hand, visual analytics allow focusing of the selection process into a limited decision space, interactively bounded by the analyst. On the other hand, the decisional tool presented enables DMs to synthesise, by means of cluster analysis, the space of solutions into a manageable number of representative ones, facilitating the process of analysing alternatives and selecting the proper one. Visual analytics allow for an ex post, dynamic selection of the criteria employed to choose the representative solutions of each cluster, as well as the number of clusters desired by the analyst, improving the extraction of knowledge.

Thus, the novelty of these methods mainly relies in the innovative combination of clustering methods and visual analytics to solve the “curse of dimensionality” problem in UVAM selection decision frameworks, contributing to alleviating burdens on the decision-making task.
In addition, the decision tool integrates bottom-up and top-down approaches in an original manner to facilitate the analysis of the alternatives being evaluated, so that we can observe the entities being assessed (up) from the point of view of a given alternative (bottom), or on the contrary, analyse alternatives (down) from the results yielded for a given entity (top).

The remainder of this report is organised as follows. In the methods section, both the decision-making framework and the assessment model are presented, along with a description of the information collection process. Then, two tools, designed accordingly to this methodology, are presented in the following section. The first one gathers and transforms the qualitative information required by the second, which articulates the decisional model for selecting UVAMs. Along with this section, the implementation of these tools on the province of Valencia, as well as the results produced by their operation, are portrayed to the reader. Finally, general conclusions are drawn in the final section.

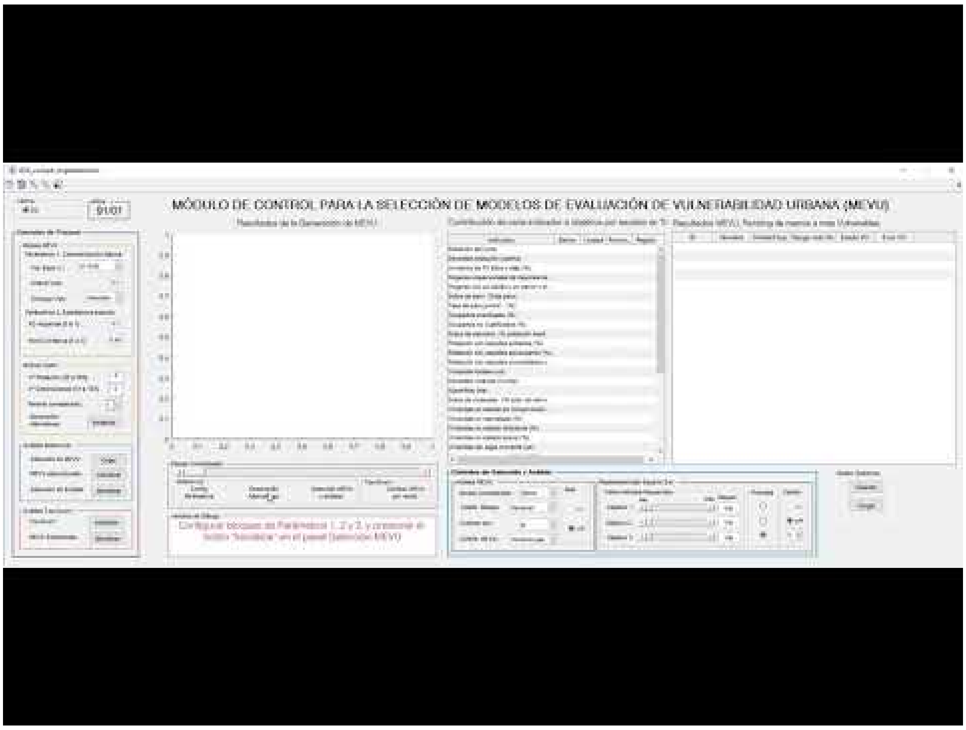
4.2 Methods

4.2.1 *Decision-making framework: addressing the curse of dimensionality*

Frequently, solving real life decision problems involves decision making, affecting different objectives, whose interests are often not aligned, and may even be opposed. This type of situation is an ideal context in which to apply MOO techniques, in order to locate the compromise solutions representing points of equilibrium. Compromise solutions are those satisfying several objectives simultaneously, such that there are no other solutions improving any of these objectives without worsening some of the others. Consequently, the rest (non-compromise solutions) of the alternatives would be irrelevant, since for any of them, we could find a compromise solution improving it in some of its characteristics, without worsening some of the others, and would therefore be preferable. This allows us to discard a large number of irrelevant possibilities, and focus the analysis on a smaller, more manageable set of solutions. This set of compromise solutions, however, would still be unmanageable, since MOO techniques usually produce large numbers of these alternatives.

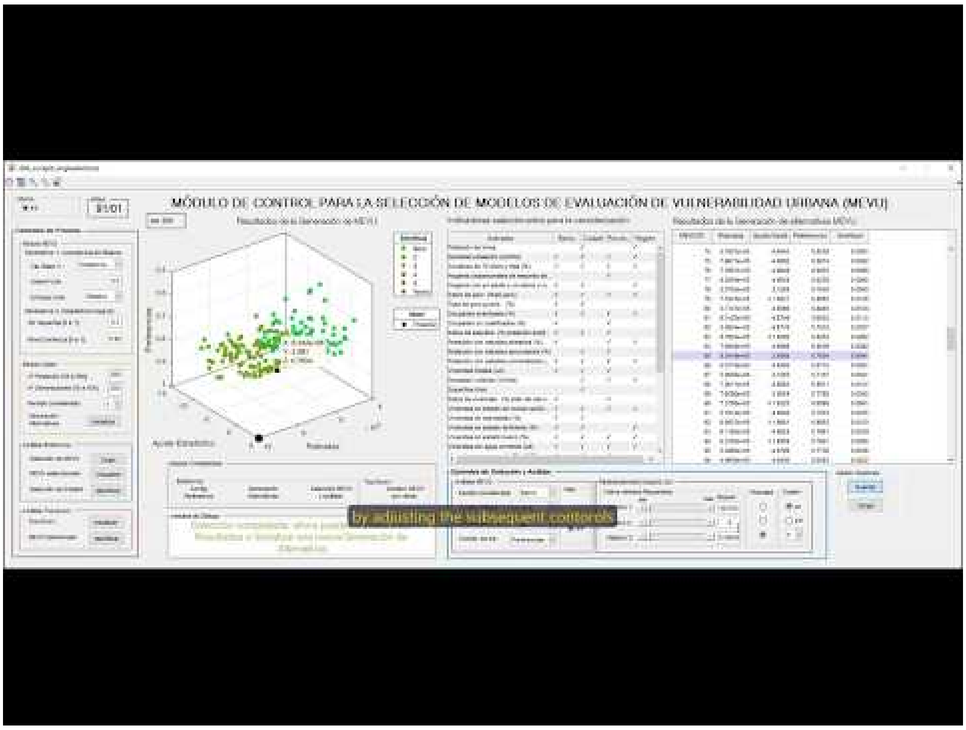
4.2.1.1 Visual analytics

In effect, the outcomes produced by each step of the method are sets of alternatives, evaluated in the light of different criteria, which are represented by a large amount of information (Lempert, 2002). To address this, interactive visual analytics use different data visualisation techniques, offering multiple, linked views of relevant information (Thomas and Kielman, 2009; Andrienko et al., 2010). Therefore, the decision tool displayed graphics and tables simultaneously, portraying relevant information to understand the trade-offs between selection criteria (Santos et al., 2017), as well as the variables included in the statistical models employed along the process (Video 4.1).



Video 4.1. Visual analytics for displaying complex information.

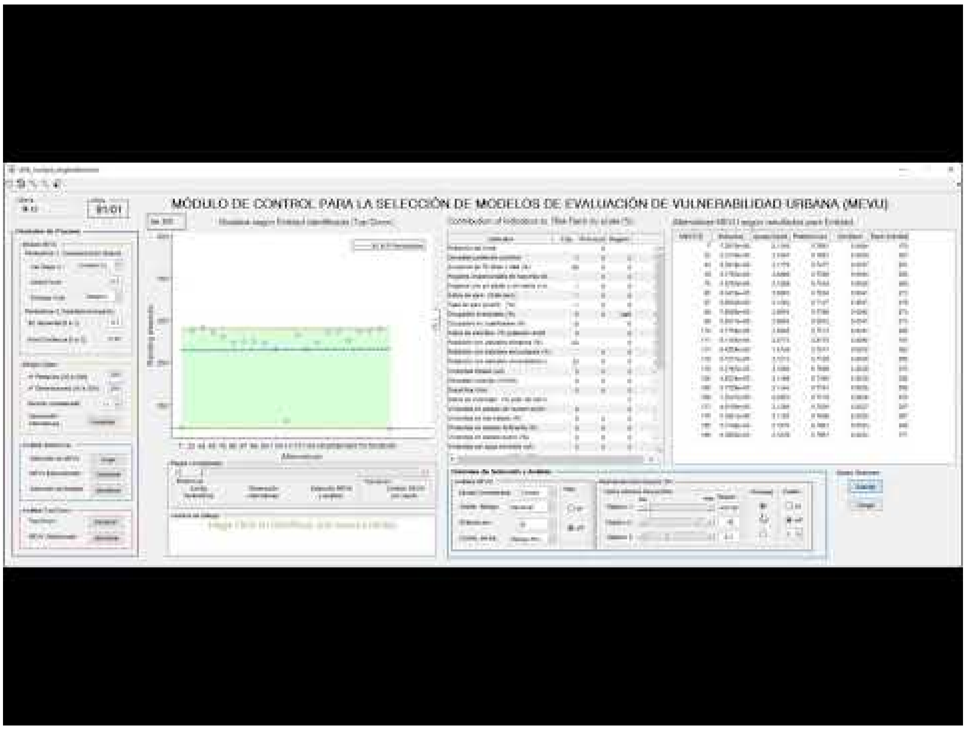
In addition, the analyst was enabled, through sliders controls, to dynamically "tune" the meeting criteria for "brushing" solutions (Inselberg, 1997). By means of this feature, the DM is enabled to focus the analysis on those alternatives meeting the required criteria, which can be dynamically set up during the process (Video 4.2).



Video 4.2. Visual analytics for bounding the space of solutions.

4.2.1.2 Cluster analysis

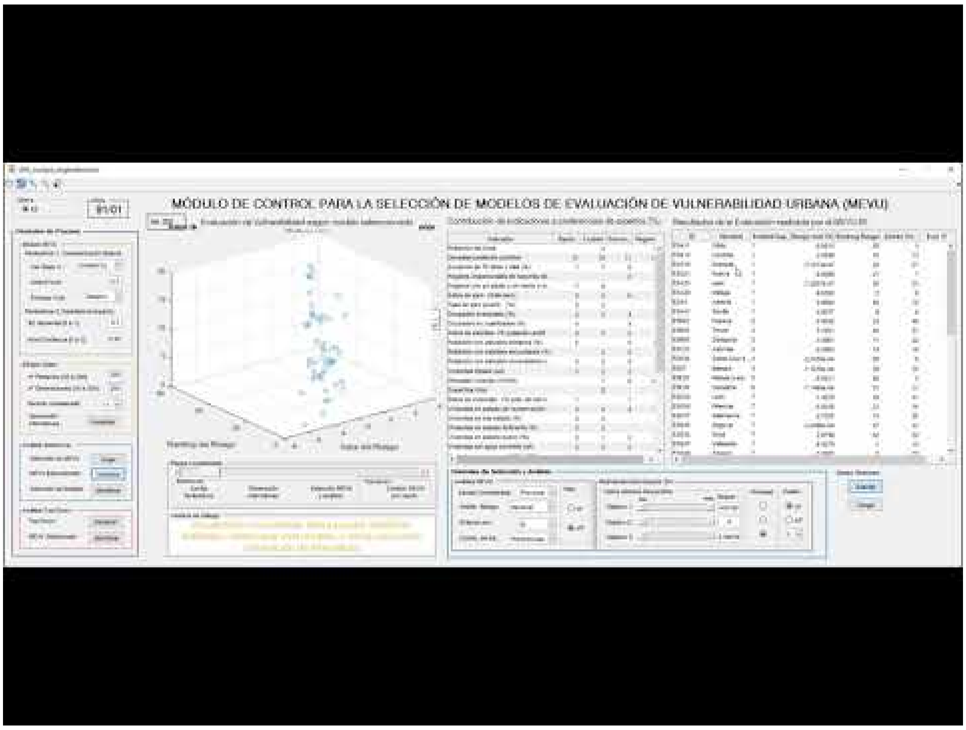
Additionally, the process allows us to synthesise this set of solutions, by clustering them into k partitions, following Lloyd's algorithm, also known as the k-mean method (Zio and Bazzo, 2011; Taboada et al., 2007). Then, it is chosen, for each cluster, its representative solution as that performing best for the desired objective, which was selected among those considered to evaluate the solutions (Video 4.3). The decision tool makes it possible to go from an unmanageable number of compromise solutions to an affordable number of relevant alternatives that, with the knowledge acquired in the process, can be handled by the decision-making team.



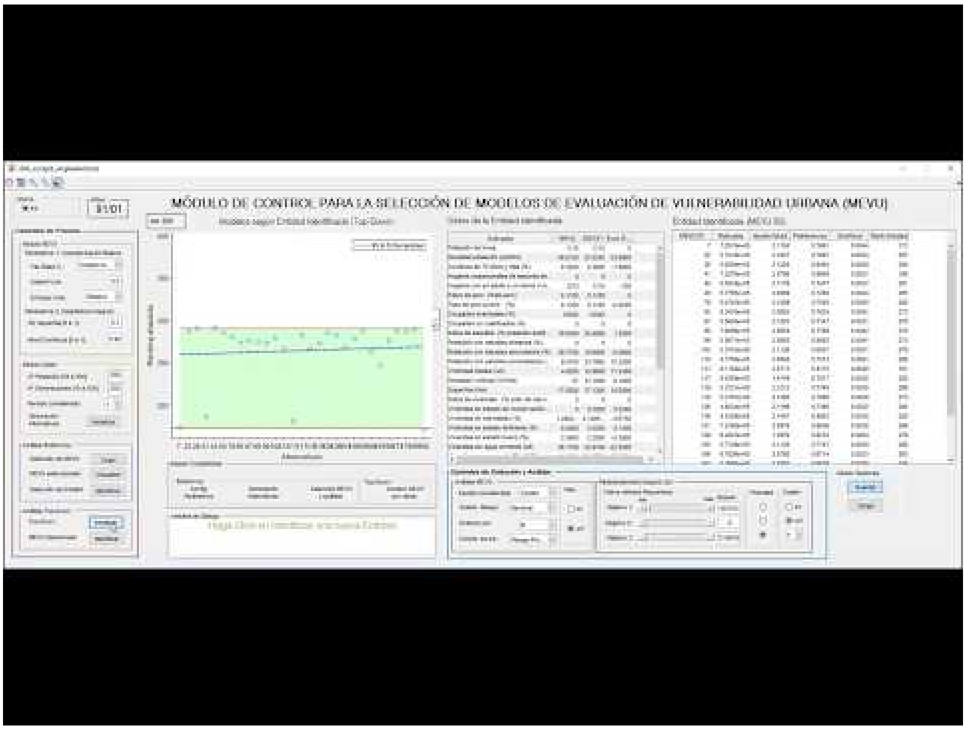
Video 4.3. Cluster analysis for synthesising the space of solutions.

4.2.1.3 Bottom-up/top-down approach

In our case, the large amount of information arose not only from the evaluation of alternatives under a set of criteria, but also from the complex nature of the solutions. For a proper understanding of both the content of any alternative, and the implications of the choice, its visualisation required a method enabling the analyst for both a bottom-up and a top-down revision of each solution. By this means, analysts are enabled to revise entities being evaluated from the point of view of the UVAM alternatives (Video 4.4) and vice-versa, to observe the alternatives from the perspective of any entity (Video 5).



Video 4.4. Bottom-up (from UVAM alternatives to entity's results) analysis.



Video 4.5. Top-down (from entity's results to UVAM alternatives) analysis.

4.2.2 *Urban vulnerability assessment framework*

Vulnerability can be defined, in broad terms, as the easiness that an entity presents to suffer from the negative effects of an event, or its difficulty in overcoming them. The concept of UV embodied in the process mainly corresponds with that considered by the Spanish Ministry of Development in its Observatory of Urban Vulnerability (OUV), 2010. According to this, an entity is vulnerable when its value, for any of the basic indicators, goes beyond the reference value, calculated as 1.5 (vulnerability threshold) times the national average (base of vulnerability). The basic indicators considered by the Ministry (OUV, 2010) to discriminate between vulnerable and non-vulnerable entities are:

- Unemployment rate. Percentage of unemployed individuals by all individuals currently in the labour force.
- Education index: Percentage of illiterate population and without education.
- Housing index: Percentage of population living in dwellings without bathroom or WC within the dwelling.

Based on this first basic characterisation, classifying the entities as vulnerable or non-vulnerable, the proposed assessment framework deepens in the analysis, establishing, through the use of principal component analysis, an assessment of the state of vulnerability (SV) at a given time (Salas and Yepes, 2018b). The higher the relationship, the more vulnerable the entity considered will be. As a result, an evaluation of each entity's SV is obtained, positioning them in the vulnerability ranking. This ranking, from least to most vulnerable, can be built following an absolute or a relative approach, depending on whether we consider the position of each entity in relation to all the other entities of the same scale, or in relation only to those dependant to the same superior entity.

The evolution of the vulnerability state, on the other hand, is considered as its variation along a given period. In our case, this evolution was studied, for periods 1 (1991–2001) and 2 (2001–2011), as the difference between the states of vulnerability at the end and at the beginning of each of these periods. Based on this evolution we obtained, through discriminant analysis, the probability of each entity to continue increasing, reducing or maintaining its level of vulnerability and, by means of linear regression, the impact with which it would change (Salas and Yepes, 2018b). These two concepts, probability and impact, combine to determine the risk, of each entity, to increase its vulnerability.

For further details of the assessment framework model and its theoretical foundations, the reader is encouraged to consult prior studies (Adger, 2006; Birkmann et al., 2014; Dominguez et al, 2011; Salas and Yepes, 2018a; Salas and Yepes, 2018b).

4.2.3 *Information collection process*

4.2.3.1 Quantitative information

The compilation of the quantitative information relative to all the municipalities of the province was downloaded from the web of the National Institute of Statistics, with the necessary data of each municipality obtained. This information was added to that already collected, regarding cities in Spain with more than 100,000 inhabitants or provincial capitals. In summary, the information gathered involved 36 indicators (Table 4.1) for each of the 403 cities (264 of which are from the province of Valencia), 52 provinces (including Ceuta and Melilla) and 19 regions (including the autonomous cities of Ceuta and Melilla as regions) that composed the elaborated database. This information was collected for years 1991, 2001 and 2011, allowing to analyse the evolution of urban vulnerability in the periods 1991–2001 and 2001–2011.

Approach Descrip.	Imp	Aspects	Imp	ID	Descripction	Importance	Rank	* OUV Importance
Socio-Economic **(SE)** Aspects	51,81	Social Structure **(SS)**	**27,68**	1	Area Population	3,64	11	0
				2	**Population density (pop/ha)**	**8,84**	**1**	0
				3	**Eder 75 years or more (%)**	**5,85**	**3**	0
				4	Households of one person older than 64 years (%)	3,68	10	0
				5	**Households of one adult and at least one minor**	**5,67**	**4**	0
		Ecomomic Strucure **(ES)**	11,49	6	* Unemployment rate (%)	4,47	5	33*
				7	Youth unemployment rate (%)	1,99	21	0
				8	Temporary employee (%)	2,02	20	0
				9	Unqualified workers (%)	3	14	0
		Educational level **(EL)**	12,64	10	* Population uneducated (%)	4,24	6	33*
				11	Population with primary education (%)	3,8	8	0
				12	Population with secondary education (%)	1,75	24	0
				13	Population with higher education (%)	2,85	15	0
Bio-Physical **(BF)** Aspects	48,19	Area Occupation **(AO)**	9,6	14	Number of dwellings(u)	1,65	25	0
				15	**Dwellings density (u/Ha)**	**6,15**	**2**	0
				16	Area (Ha)	1,8	22	0
		Dwellings Condition **(DC)**	11,75	17	* Dwellings rate (% Population with no WC in the dwelling)	1,05	31	33*
				18	Dwellings in ruin condition (%)	3,4	13	0
				19	Dwellings in bad condition (%)	2,6	17	0
				20	Dwellings in deficient condition (%)	1,77	23	0
				21	Dwellings in good condition (%)	1,29	30	0
				22	Dwellings without running water (%)	1,64	26	0
		Dwellings Size **(DS)**	**16,37**	23	Dwellings with less than 30 m2 (%)	2,75	16	0
				24	Dwellings total usable surface (m2)	2,5	18	0
				25	Mean usable surface by dwelling (m2)	3,88	7	0
				26	Mean usable surface by habitant (m2)	3,44	12	0
				27	Number of rooms by dwelling (u/dwell)	3,8	9	0
		Dwellings Usage **(DU)**	5,63	28	Main Dwellings (u)	1,05	32	0
				29	Empty Dwellings (u)	2,34	19	0
				30	Owned Dwellings (u)	0,76	34	0
				31	Rented Dwellings (u)	1,48	28	0
		Dwellings age **(DA)**	4,84	32	Dwellings in builds built before 1951 (%)	1,49	27	0
				33	Total buildings (u)	0,44	36	0
				34	Buildings older than 30 years (u)	0,51	35	0
				35	Buildings older than 50 years (u)	1,45	29	0
				36	Buildings older than 80 years (u)	0,96	33	0

Table 4.1 Relative Preferences of Experts and comparison with Preferences of the Urban Vulnerability Observatory

4.2.3.2 Qualitative information

The analytic hierarchy process (AHP) is a multi-criteria technique usually employed to collect relative preferences between criteria based on verbal judgments (Khalil et al., 2016, Pellicer et al., 2016, Kubler et al., 2016; Sierra et al., 2018). In the AHP, the preferences between the criteria within a group are determined by the principal right eigenvector method (Saaty, 1990). As for the hierarchical structure, independence between elements of different groups was assumed. In addition, the hierarchical composition principle was followed, multiplying successively the relative preferences of the dependant elements by the weight of the element on which they depend, to obtain the total priorities.

The AHP allows for the transformation of experts' verbal judgment into mathematical language, by pairwise comparisons on a set of criteria. However, the number of criteria being compared should not exceed five, since from this point, it becomes very difficult for a person to relate the set of concepts to each other (Saaty, 1990). Given that our case entails the comparison of 36 different criteria, they were structured in three levels, so that only in one case is the number of criteria to be compared greater than five. Basically, the structure adopted was a transposition of the conceptual framework adopted by the Spanish OUV, to which some indicators were added.

The AHP processes are, in many occasions, articulated in two steps, in which expert judgments are first collected through survey and then processed, only to discover, on many occasions, that judgments had an unacceptable consistency index. This leads to the repetition of the survey if possible, or to review the judgments maintaining priority in the trials (Singh and Nachtnebel, 2016). Both alternatives entail time consumption and quality reduction. To avoid this problem, an application was developed in the form of computer software that informed the participants, as they made their judgments, about whether these were consistent or not, allowing experts to revise their judgements until they became acceptable (Video 4.6).

4.3 Results

The previous methodology has been implemented in the form of two decision tools that allow its use by experts and DMs. The first one allows us to collect the subjective preferences of the experts, while the second operates the complete process of selection of UVAM alternatives.

4.3.1 *A tool for evaluation of relative preferences*

4.3.1.1 Description of the tool for gathering relative preferences

A computer application, programmed in Matlab, has been implemented, which facilitates obtaining expert preferences. This tool, based on the AHP multi-criteria decision technique, instantly evaluates the consistency of the judgments, allowing their review at the moment and guaranteeing that the evaluation issued by the expert meets the necessary technical requirements and is suitable for its aggregation to the process. The whole process of judgment input and elicitation of preferences can be followed in Video 4.6.

Video 4.6. Tool for collecting expert relative preferences on indicators used for UVAM.

As indicated in section 4.2.3.2., the AHP method was used to gather the preferences of the experts and consult about the indicators that, in their opinion, are of more help when it comes to characterising UV.

Figure 4.1 allows us to appreciate that preferences for the socio-economic (SE) or biophysical (BF) approaches are quite similar, suggesting the use of comprehensive approaches, which make use of both. Regarding the level of aspects, the two most representative are the social structure (SS) and the dwellings size (DS) (Table 4.1). These aspects are the most preferred for the sociological and BF approaches, respectively, in line with the equality in the distribution of importance between both points of view. It is significant, among the biophysical aspects, the lower importance bestowed to the dwellings age (DA) and dwellings usage (DU) aspects in comparison with the other. The SS is, in contrast, clearly preferred to the other aspects of the SE approach. The aspects of both the BF and the sociological approaches have a great heterogeneity in the value of their preferences, although these differences are more marked in the sociological approach.

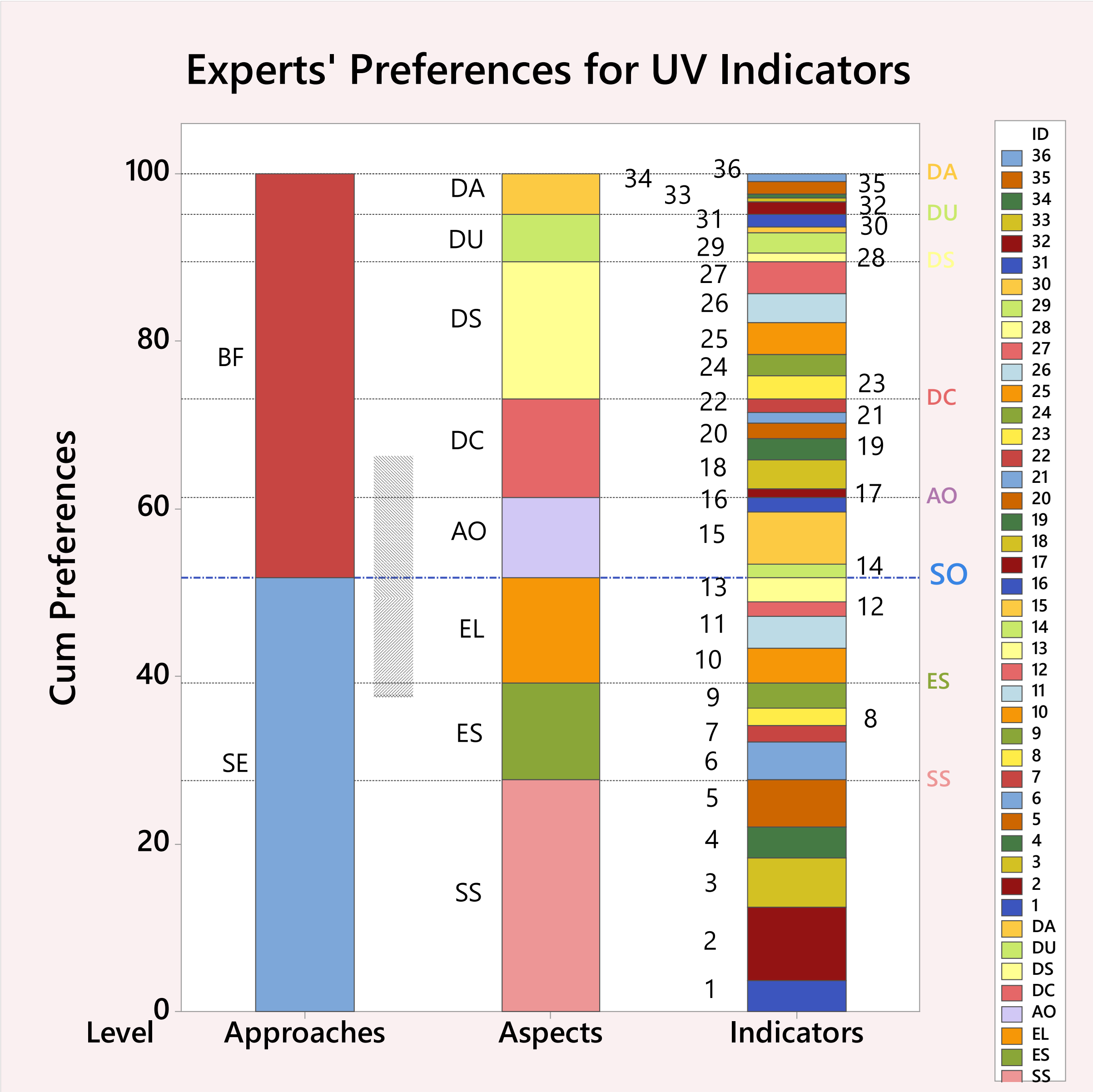


Figure 4.1 Relative preferences of experts for UV assessment indicators

At the level of indicators, the results of the analysis allow us to state that the most relevant, for the experts consulted, are those related to density, whether it is population density (indicator no. 2, population density (population/ha), preference value = 8.84) or the density of dwellings (indicator no. 15, dwellings density (Viv/Ha), preference value = 6.15). In addition, each of these indicators are the most representative in their respective classes, namely, SS and area occupation. The next two indicators in importance are also part of the SS aspect. Thus, the third and fourth positions in the ranking by importance from highest to lowest, are occupied by indicators 3, elders of 75 years or more (%), and 5, households of one adult and at least one minor (%), with some values of relative importance of 5.85 and 5.67, respectively. As can be seen in Figure 4.2 Preferences for indicators, there are up to 11 indicators above the upper limit of the confidence interval of the mean (HighCI), and 18 below, which gives an idea of the range of possible values that the indicators can adopt.

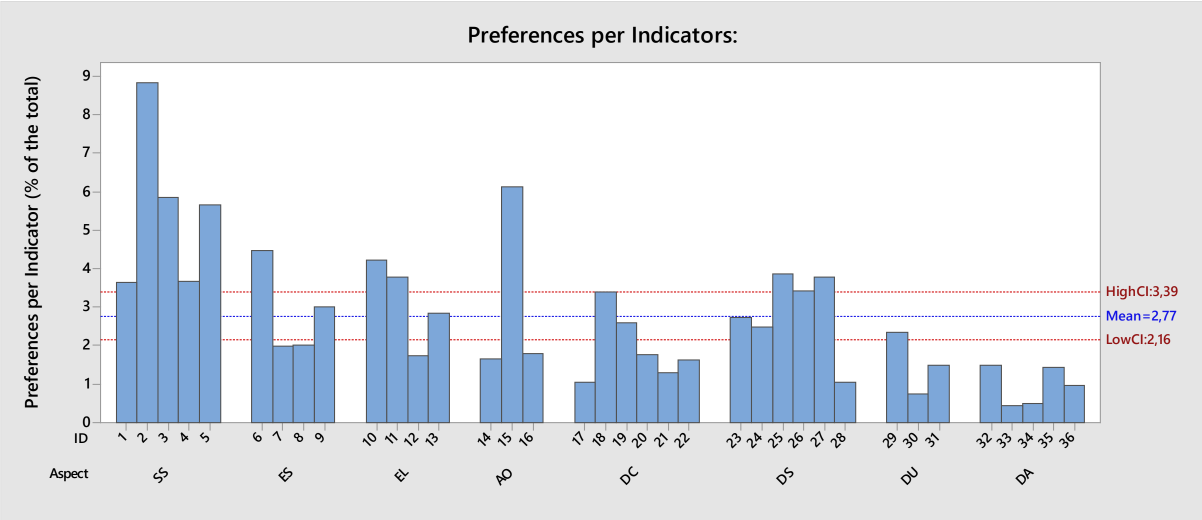


Figure 4.2 Preferences for indicators

Consistent with this idea, the values of both the first quartile (Q1 = 1.4825) and the third quartile (Q3 = 3.77) fall outside the confidence interval. This indicates that the differences in relative importance between indicators cannot be disregarded or assimilated to an average value.

4.3.1.2 Discussion of the results of expert judgment

This heterogeneity in preferences assigned by experts to UV indicators contrasts with the assumptions on which all the evaluation available in the OUV are based. Once the basic classification to identify vulnerable entities has been carried out, a series of intensity levels of the vulnerability state are estimated, considering first that all (unemployment, studies and housing) are equally important, and later that the housing indicator has a position subrogated to the rest (Table 4.2).

This surrogate position seems to have no other purpose than to allow the evaluation process to be staggered in a pairwise comparison of concepts, through double-entry matrices, which would be unfeasible if all three criteria are equally important (as initially considered by the OUV, on the other hand). The process is articulated using the result of the comparison of the first pair as a concept to be compared with the next in another pairwise comparison, whose result could in turn be compared with another concept if it existed, and be repeated according to the number of concepts considered as basic. In this process, there is no logical consistency, nor is there any relationship with the conceptualisation of UV employed by OUV.

		First Comparison:			
Population uneducated	(C): >2.5xNM	Severe Vulnerability	Severe Vulnerability	Severe Vulnerability	Critical Vulnerability
	(B): RV-2.5xNM	Slight Vulnerability	Medium Vulnerability	Medium Vulnerability	Severe Vulnerability
	(A): NM-RV**	No Vulnerability	No Vulnerability	Medium Vulnerability	Severe Vulnerability
	(0): 0-NM*	No Vulnerability	No Vulnerability	Slight Vulnerability	Severe Vulnerability
Thresholds for values of indicators		(0): 0-NM	(A): NM-RV	(B): RV**-2.5xNM	(C): >2.5xNM*
		Unemployment rate			

	From 1st Comparison:	Second Comparison:				
Population uneducated + Unemployment rate	Critical Vulnerability	Critical Vulnerability	Critical Vulnerability	Critical Vulnerability	Critical Vulnerability	Critical Vulnerability
	Severe Vulnerability	Severe Vulnerability	Severe Vulnerability	Severe Vulnerability	Critical Vulnerability	Critical Vulnerability
	Medium Vulnerability	Medium Vulnerability	Medium Vulnerability	Medium Vulnerability	Severe Vulnerability	Critical Vulnerability
	Slight Vulnerability	Slight Vulnerability	Slight Vulnerability	Slight Vulnerability	Medium Vulnerability	Severe Vulnerability
	No Vulnerability	No Vulnerability	No Vulnerability	Slight Vulnerability	Slight Vulnerability	Medium Vulnerability
Thresholds for values of indicators		(0): 0-NM*	(A): NM-RV**	(B): RV-4xNM	(C): 4xNM-4xNM	(D): >8xNM
		Dwellings rate				

* NM= National Mean

** RV=Reference Value (1.5xNM)

Table 4.2 Criterion followed in the Observatory of Urban Vulnerability to estimate the State of Vulnerability of the entities (General Methodological Synthesis of the Catalog of Vulnerable Districts and Basic Indicators of Urban Vulnerability)

The pairwise comparison process used by the OVU for the evaluation of the state of vulnerability consists of assigning levels of vulnerability (0, A, B, C or D) to each basic indicator, based on certain, not justified thresholds (Table 4.2). Then, a double-entry matrix is built with these levels as abscissa and ordinate axes. The value of each position in the matrix will be the greatest (most unfavourable) of comparing the values of its ordinate and abscissa, except in the case that both are the maximum possible of each concept, in which case the value assigned to that position is a higher grade.

On the other hand, none of the indicators considered in the analysis of the vulnerability observatory to estimate the intensity of vulnerability is found within the aspects considered most influential by the experts consulted (Table 4.1).

All of the above suggests that it would be convenient to rethink the methodology used by the OUV, so that the different importance of the indicators is taken into account when assigning vulnerability intensity, and the logical consistency of the process is improved, as the concordance with the concept that should be characterised.

4.3.2 A tool for selecting UVAM

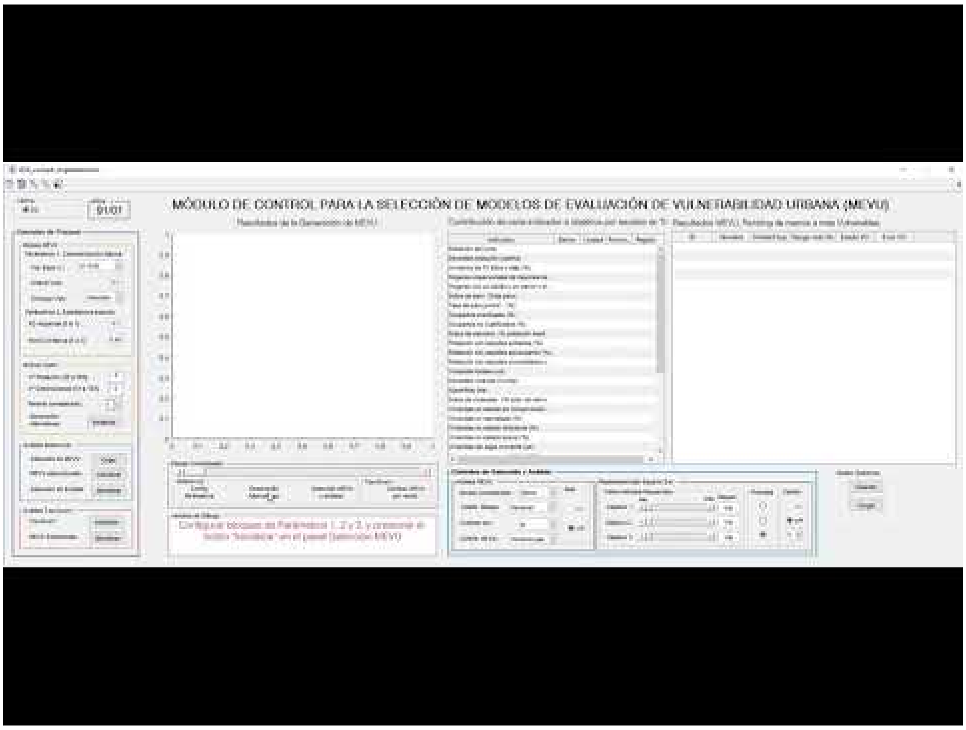
4.3.2.1 Description of VisualUVAM

As a result of the above, a tool was designed that allows finding, from an unmanageable set of feasible solutions (permutations of the 36 indicators in each of the four scales), a number, chosen by the decision-making team, of relevant solutions that synthesise the set of compromise solutions. In these, each solution represents a model of urban characterisation according to the latest trends in urban strategic planning. This tool has taken form as a guided process, through a computer application programmed in Matlab, in which the DM and the software interact to progressively complete a series of stages, which result in the selection of the appropriate characterisation model. The guidance of the process is achieved by structuring it in a series of stages, which must be completed sequentially, and starting from a bottom-up approach, to finish, optionally, with a top-down approach (top-down), allowing us to take advantage of the benefits that each one provides.

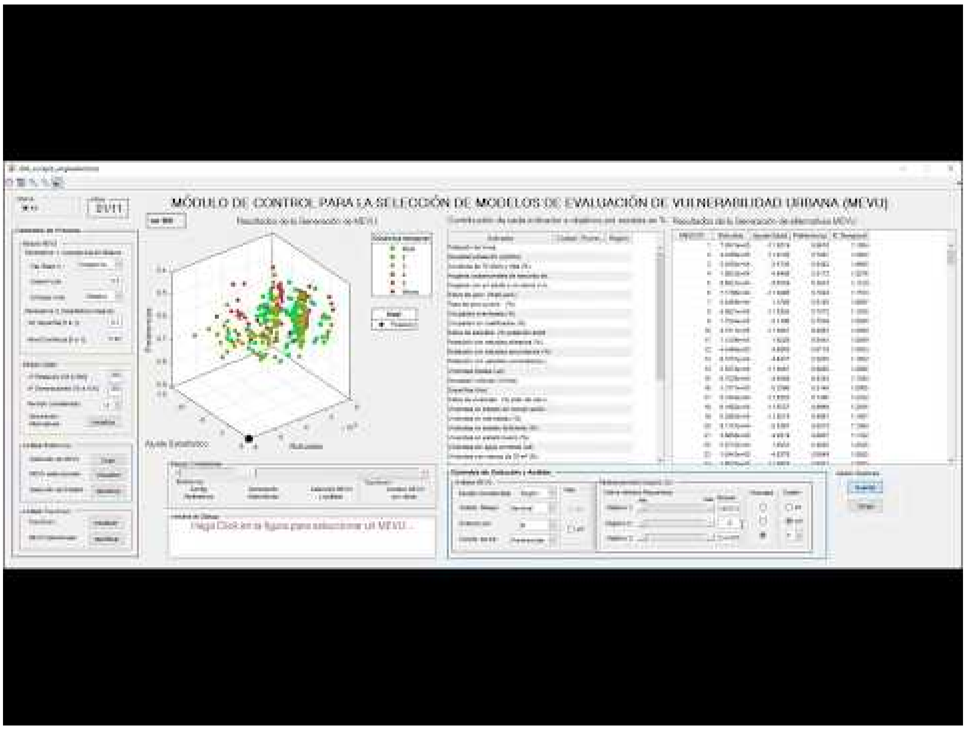
The operation of the tool for the selection of UV models is described below. The results obtained throughout the process are the following:

- Generation of alternatives, evaluated according to the criteria defined for that purpose (Stage 2, Video 4.8, Period 2, Video 4.9).
- Visualisation of the results of each model (bottom-up analysis) for each scale (Stage 3, Video 4.3):
  - Risk assessment to increase vulnerability.
  - Ranking of risk.
  - Ranking of the SV of each entity at the end of the period analysed.
  - Evolution of the vulnerability state in that period**.**
- Visualisation of the contribution of the indicators incorporated in each scale of the model analysed, to the following objectives (Stage 4, Video 4.4):
  - Preferences: relative importance of each indicator in the score obtained in this objective.
  - Statistical adjustment: coefficients of the discriminant function of the vulnerable identification class.
  - Impact of risk: coefficients of the linear regression.
  - Probability of risk: coefficients of the discriminant function of the class evolution vulnerability.
- Visualisation of alternatives based on the result produced, in each of them, for a reference entity (top-down analysis) (Stage 4, Video 4.5).
- Resizing of the solution space according to the requirements established for each criterion (Stage 5, Video 4.3).
- Synthesis of solutions through cluster analysis and selection of the representative solution of each cluster (Stage 5, Video 4.3; Period 2, Video 4.10).
- Visualisation of entities through maps of state and risk of vulnerability (Period 2, Video 4.11).
- Selection of model for assessing UV in Spain in general, and in the province of Valencia in particular (Period 2, Video 4.10).

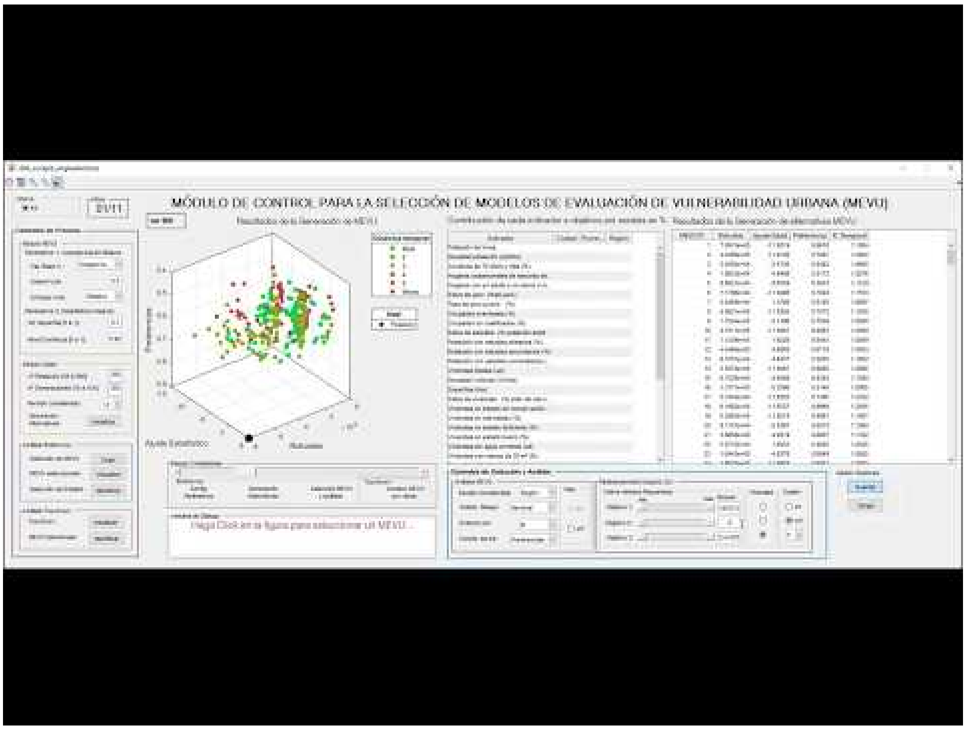
As an illustration of the tool obtained, the complete process for the selection of an UVAM is described in Videos 7, 8, 1, 2, 4, 5, 3, 9, 10 and 11.



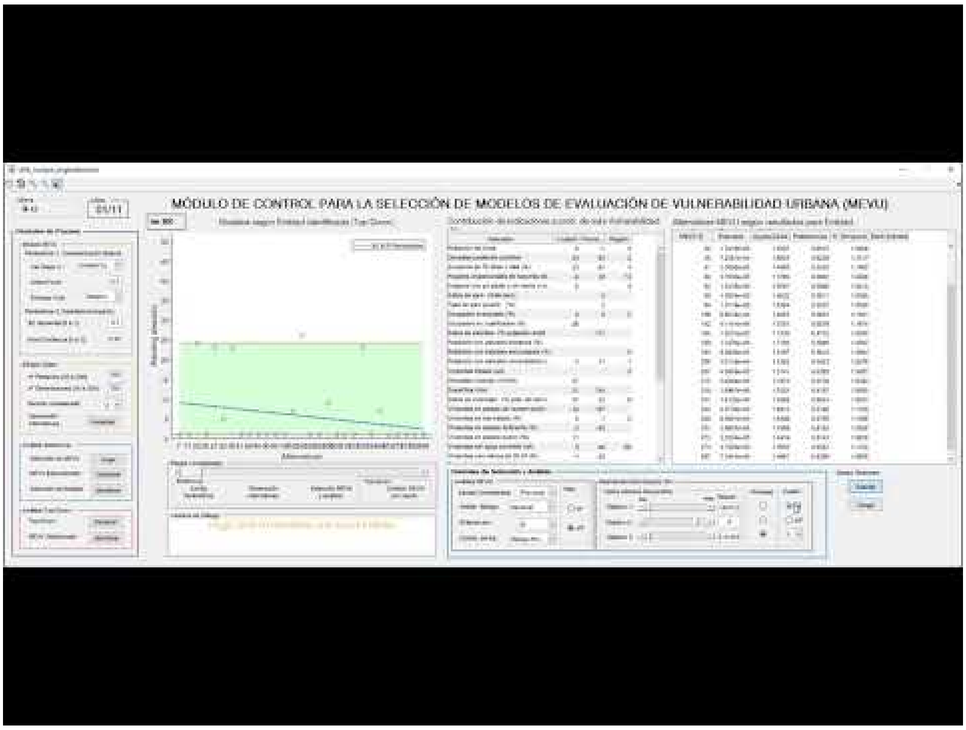
Video 4.7. Basic configuration of UVA framework



Video 4.8. Generation of UVAM alternatives for Period 1.



Video 4.9. Generation of UVAM alternatives for Period 2.



Video 4.10. Synthesis of solutions and selection of an UVAM for Period 2.

Video 4.11. Visualisation of entities through maps for Period 2.

- **Stage 1. Configuration of parameters (Video 4.7):**

In this stage, the desired values are introduced for the basic characterisation parameters, described in section 4.2.2, UV assessment framework:

  - Value taken as a base of vulnerability
  - Vulnerability threshold
  - Vulnerability Approach

The statistical requirements that the regression with which the impact value is determined, was used to calculate the risk of each entity, can also be configured.

- **Stage 2. Generation of alternatives (Video 4.8):**

This stage is controlled with two parameters, which define the number of alternatives to be handled, and the number of iterations that must be followed in the search process. The greater the number of alternatives and iterations, the better the quality of the search will be, but it will require more computing time. From 200 alternatives and 200 iterations, models with an acceptable quality are obtained. Once the desired values have been entered in each parameter, the generation of alternatives can be initialised. As a result of this generation, a set of compromise solutions was obtained.

- **Stage 3. UVAM selection and analysis:**

Once the set of alternatives has been generated (Video 4.1), it can be resized by specifying the required values for each objective (Video 4.2) or synthesised by cluster analysis (Video 4.3). Once the set of alternatives on which the analysis would be focused is defined, the analyst can explore them using the controls in the bottom-up analysis panel. As an example, the one that presents the best statistical adjustment was selected.

Next, the analyst can visualise the results that the model produces (Video 4.4). In this case, the graph and the table of results represent the identification values of the entity, the superior entity to which it belongs, risk assessment, risk ranking, state ranking at the end of the period and evolution of the state throughout the period, for each entity for the selected scale.

- **Stage 4. UVAM contextualisation by results:**

The analyst can also perform a top-down analysis of the UVAM alternatives, thereby evaluating these from the perspective of the assessment results they produce on the entities analysed instead of observing them from the objectives/criteria employed to generate them (bottom-up).
In our case, by making use of visual analytics, the user can focus on those solutions with positive values in the objective of statistical adjustment (they comply with the statistical conditions set for the regression of the impact), and with a level of coincidence with the preferences of the experts of at least 70% (Video 4.5).
As can be observed, for this entity the set of alternatives generated produces positions that in 90% of the cases are located between the values 171 and 289 of the ranking. In order to obtain a more manageable set of alternatives, this set of solutions was synthesised (Video 4.3).

- **Stage 5. Selection of alternatives:**

If, for example, we consider that for a model to be acceptable it should that have a positive statistical adjustment and is at least 80% close to the preferences of the experts, and at the same time, it should be the most robust among the synthesised solutions, we would choose the model with ID 118. In this model, the city employed to conduct our top-down analysis would occupy position 266, that is, an intermediate position within the possible range (171–287). From the bottom-up point of view, comparatively with the rest of the representative solutions of each cluster, this solution would have a good behaviour in the subjective preference criteria (2nd), as well as being the second best in the robustness criterion. This is not so in the statistical adjustment criterion, where it turns out to be intermediate.

4.3.2.2 Discussion of the results yielded by the VisualUVAM tool:

From the ID 118 model, the generation process of alternatives has been repeated for the second period. In this case, the 4th objective allows us to obtain knowledge of the degree of the relationship between the new alternatives generated in Period 2, and the alternative 218 selected in Period 1. The alternative selected in Period 2 is that corresponding to ID 274, which presents one of the best preferences among the models with positive statistical adjustment (Video 4.9 and Video 4.10).

The results of the analysis at the regional, provincial and municipal levels are attached in Annex 1. The vulnerability maps at the provincial level of model 274 are represented in figures 3 and 4, as well as in Video 4.11).

Absolute Ranking:

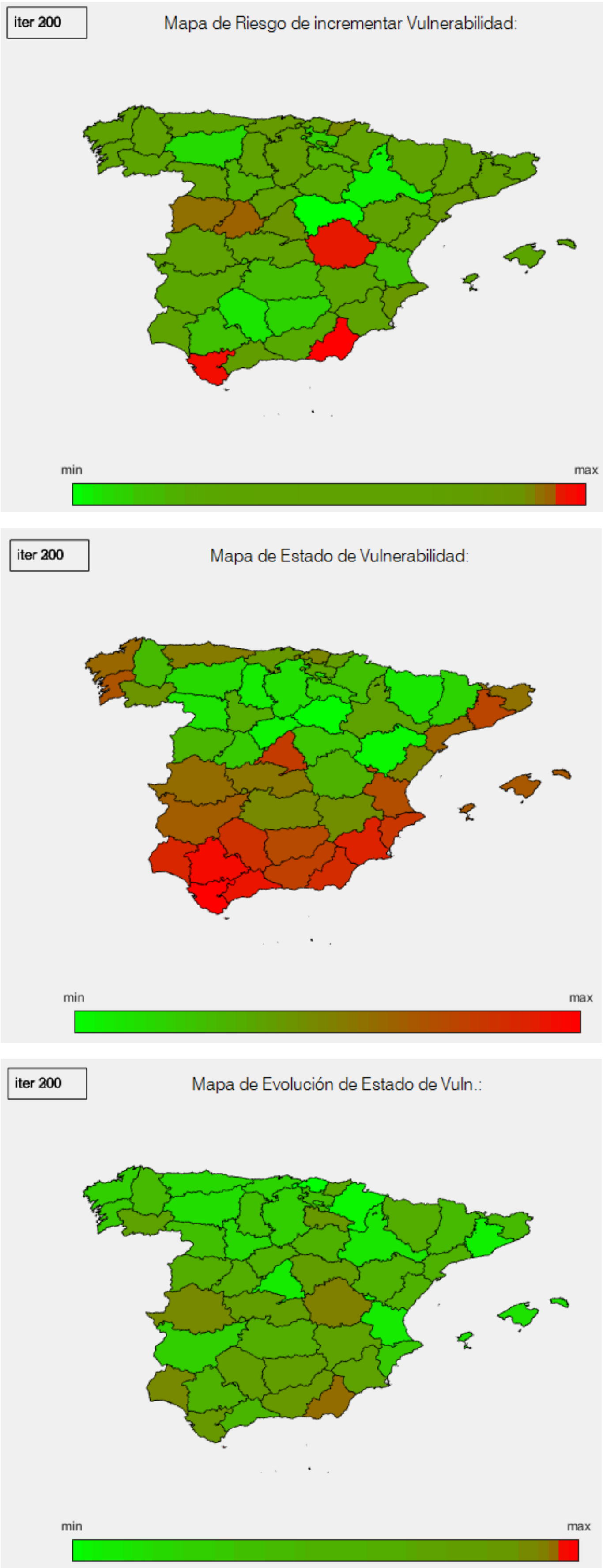


Figure 4.3 Absolute maps of vulnerability

Relative Ranking:

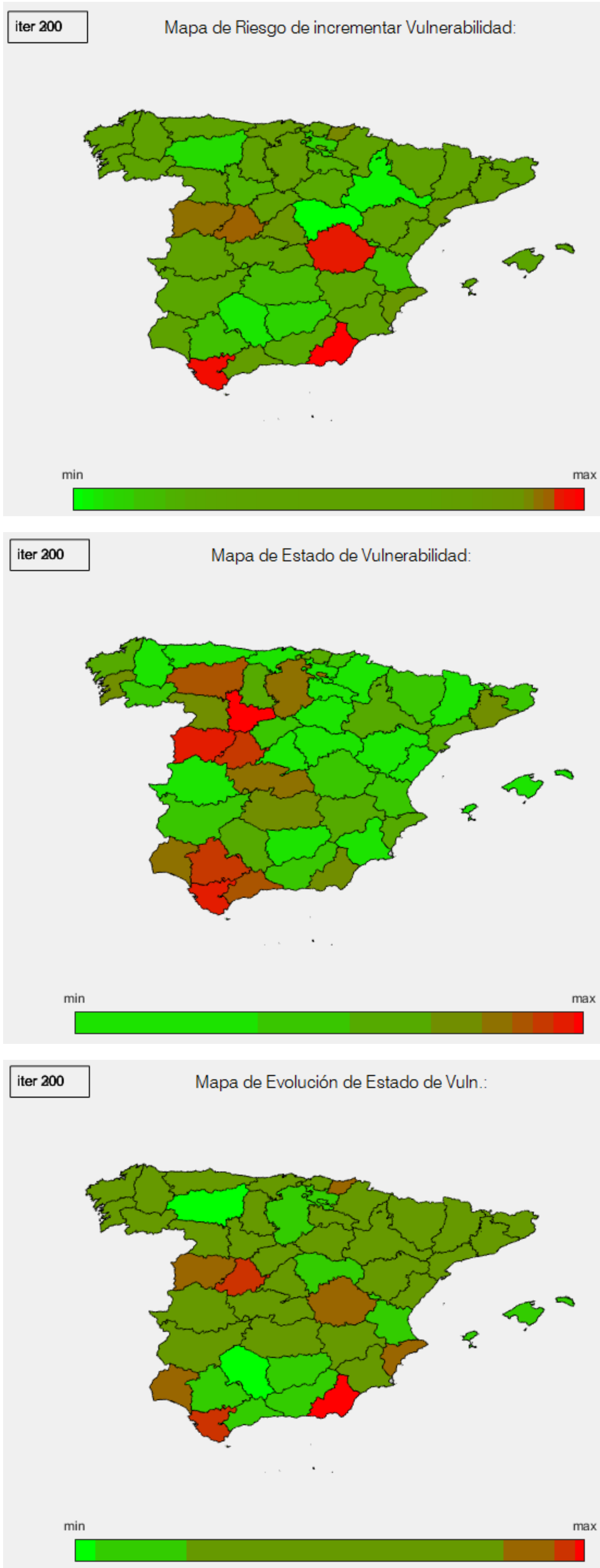


Figure 4.4 Relative maps of vulnerability

These maps allow each province to be contextualised both at the national level (absolute ranking, Figure 4.3 Absolute maps of vulnerability) and at the regional level (relative ranking, Figure 4.4). These maps are the graphic expression of Annex 1, which shows the results of both the absolute and relative analysis for municipalities, provinces and regions.

It can be seen how, according to model ID 274, there are provinces like Cuenca whose state of vulnerability (SV), at the end of Period 2 (2001–2011), is moderate in absolute terms and that, however, present a high risk of worsening. On the contrary, provinces such as Madrid, Valencia, Seville and Barcelona have a very high SV, and at the same time, a reduced risk of worsening. There are even cases like the one in Córdoba which, with a very high level of vulnerability, also present a negative risk of reducing their levels of vulnerability, which can be interpreted as an opportunity for improvement. In the case of Córdoba, this tendency towards improvement is reflected in the SV evolution maps, especially in the case of relative ranking.On the contrary, there are provinces such as Almeria with very high levels both in their SV, and in their risk, and which also show a very unfavourable SV evolution, especially in comparison with the rest of the provinces of its region (relative ranking).

In the case of the province of Valencia, we can observe how its SV (Figure 4.5) is better and worse than that of Alicante and Castellón, respectively. However, its evolution (Figure 4.6) has been the best in its region, presenting, in addition, the lower risk of increasing its vulnerability (Figure 4.7). Regarding their municipalities, their results are detailed in Annex 1 and in the corresponding maps.

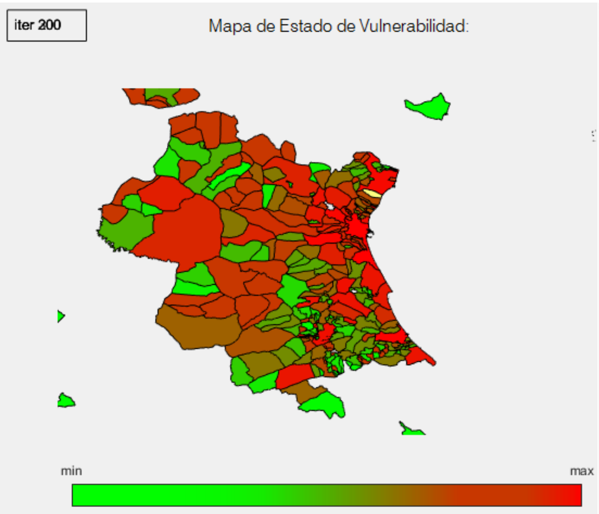


Figure 4.5 Map of Valencia's state of vulnerability

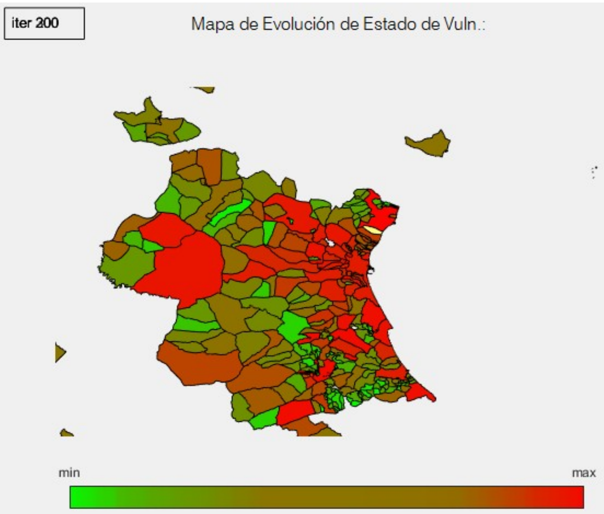


Figure 4.6 Map of Valencia's evolution of its state of vulnerability

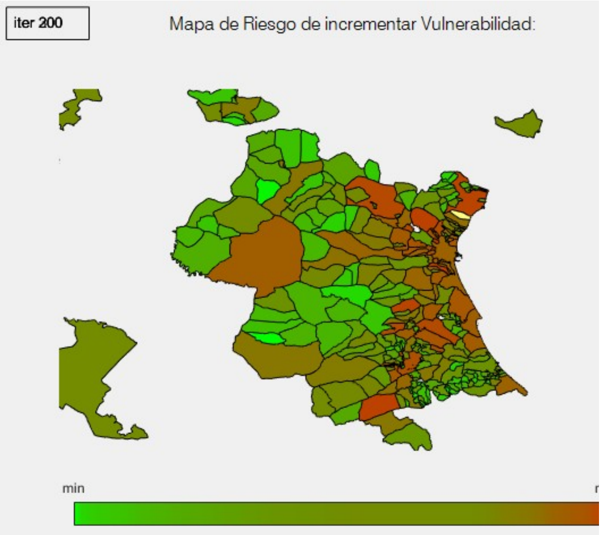


Figure 4.7 Map of Valencia's risk of vulnerability

On the other hand, UV is studied from different points of view: its state at a given moment, the probability that this state will be increased, and the intensity, or impact, with which this change would occur. The determination of each of these values has been made by applying statistical techniques to the collected data, which allows using the coefficients provided by each technique to understand how the selected characterisation model works.

The contribution of each indicator of the selected model selected to the different aspects of vulnerability (preferences, SV and risk of vulnerability), by scales (city, province and region), is reflected in Video 4.11.

The variation in the contribution of indicators can be observed, evidencing their different degrees of importance, which on the one hand underpins the considerations of experts (section 4.3.1.2) while on the other hand contrasts with the approach of the current analysis in the OVU, where the criteria used to identify vulnerable entities are considered with the same relative importance. It contrasts, as well, that two of the three basic indicators, used by the UVO to discriminate between vulnerable and non-vulnerable entities, do not appear among the factors that significantly contributes to increase UV.

4.4 Conclusions and further research

Throughout this research, a method for selecting urban vulnerability assessment models has been developed to obtain a tool that allows for the generation of results according to the latest trends in the field of urban strategic planning. The process finds relevant alternatives that satisfy multiple criteria simultaneously, takes advantage of the integration of quantitative and qualitative information, incorporates expert judgment in the generation of alternatives, explores a wide universe of alternatives and synthesises them into a manageable number of options. The proposed formulation of the urban vulnerability phenomenon considers its dynamic aspects over both time and the administrative structures in which it develops, offering a consistent and comprehensive assessment along the scales of neighbourhood, municipality, province and region, and allows contextualising the entities evaluated in different areas.

The method takes advantage, as well, of the joint use of bottom-up and top-down approaches in the decisional process, allowing an analysis of the alternatives from the point of view of the characteristics that originate them, as well as from the results they produce.
Additionally, this work also presents a tool, developed in the form of software, that facilitates the collection of expert preferences, allowing them to check the consistency of their judgments in real time, review them before its submission and therefore improve the quality of this analysis.

The analysis of the qualitative information collected has served to evaluate the relative preferences of the set of indicators used to characterise urban vulnerability. These results indicated very marked differences in the importance both among indicators, and among the aspects in which they are grouped, which should be considered when assessing the level of urban vulnerability. For the experts consulted, the most relevant indicators in order of priority are the population density (inhabitants per hectare), the density of housing (Viv/Ha), the percentage of elderly people aged 75 and over (%), and the percentage of unipersonal households over 64 years of age (%). At the level of aspects, the most important are the social structure and dwellings size. These results contrast strongly with the criterion used in the analysis of the Spanish Observatory of Urban Vulnerability, based on only three indicators, considering them equally important. The quantitative analysis carried out with the aid of the tool for selection of urban vulnerability assessment models also shows significant differences in the importance of the indicators available. The model selected in the case study portrays the differences, in their relative importance, of the indicators used to assess both the state of vulnerability, as well as the probability or impact associated with the risk of each entity to increase its level of urban vulnerability. In addition, the absence of basic indicators in the set of indicators with the greatest incidence in increasing vulnerability reinforces the suggestion that it is necessary to review the suitability of the current set of basic indicators.

In the case of the province of Valencia, whose results are detailed in Annex 1, we can see that for the model selected in the case study, its state of urban vulnerability is better and worse than those of Alicante and Castellón, respectively (vulnerability maps to provincial level of model 274). Alternatively, its evolution has been the best in its region presenting, in addition, the lower risk of increasing its vulnerability.

The quantitative analysis offers an assessment of the state of urban vulnerability of each entity at the end of each period considered (1991–2001 and 2001–2011), the evolution of that state throughout each period, and the risk of each entity of worsening their level of vulnerability. For the selected evaluation model, the process offers information about the contribution of each indicator to the degree of coincidence with the preferences expressed by the experts, as well as its effect on a series of aspects of the model. These aspects are the probability of being vulnerable, the probability of becoming more vulnerable, and the impact of this change. For the assessment model selected, these indicators can be considered as guidelines to be followed in order to avoid a worsening of urban vulnerability levels, or to improve existing ones.

Despite the importance of the contributions indicated, the method developed during this research still contains limitations, whose overcoming would lead to several improvements. The assessment framework employed is based on that of the Observatory of Urban Vulnerability, which proposes a basic classification of vulnerable or non-vulnerable entities based on the exceeding of a reference value in any of the basic indicators. However, the results of this research force us to question the suitability of the selected indicators. Therefore, it is necessary to deepen the study of the most appropriate set of basic indicators.

On the other hand, the employment of the indicators established in the Observatory of Urban Vulnerability limits the availability of updated data to periods of 10 years, which is when the population and housing censuses are taken. As indicated, urban vulnerability is dynamic in relation to time, and therefore varies throughout time. While it is true that this variation is slow, it would be advisable to explore the possibility of using alternative indicators, with a shorter update period, and therefore allowing the model to be replenished more efficiently.

As stated, the designed method incorporates participatory processes in the bottom-up phase, by adding to it the subjective preferences expressed by the experts consulted. In this way, the experts are involved in the process, and can check to what extent each urban vulnerability assessment model alternative makes use of the indicators preferred by them. However, the top-down analysis stage lacks this feature. Given that this stage is of great help for an adequate understanding and resolution of the decisional problem, the absence of participation in the top-down analysis reduces the advantages derived from its implementation. To incorporate the opinions of the experts throughout the entire process, it would be necessary to introduce their criteria not only as an objective in the generation of alternatives (bottom-up), but also in their evaluation from the results (top-down). This can be achieved by properly structuring the set of entities so that they can be evaluated by the experts. In this case, the experts would have to assess the level of relative vulnerability of the different entities involved, which would allow the construction of a subjective vulnerability ranking. This ranking could be used as a reference, comparing it with the ranking of each of the alternatives proposed by the tool, and thus evaluating all the generated models based on the level of coincidence of their results with those determined by the experts, adding this information to the set of selection criteria.

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Capítulo 5

Evaluation of risks and opportunities arising from relational uncertainties associated with infrastructure planning - Evaluación de riesgos y oportunidades derivados de incertidumbres relacionales asociadas a la planificación de infraestructuras

Artículo 4: MS-ReRO and D-ROSE methods: assessing relational uncertainty and evaluating scenarios' risks and opportunities on multi-scale infrastructure systems.

Publicación

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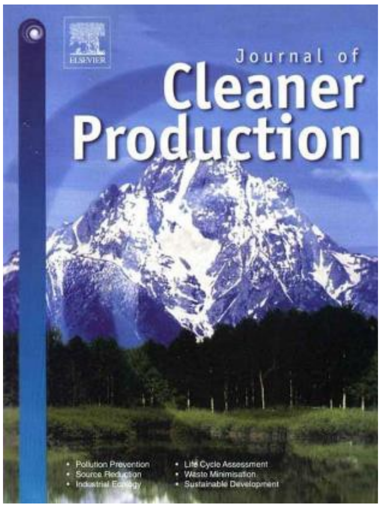

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Abstract

There is a growing interest in model-based decision support systems contributing to strategic planning. The application of these in the case of urban infrastructure planning requires methods specifically aimed at addressing the relational uncertainties arising from the complex, multi-scale, nature of this field. This study presents UPSS, a comprehensive urban planning support system integrating the generation of planning alternatives, the evaluation of alternatives under a set of relevant scenarios selected dynamically in a cognitive way, and the proposal of policies to accompany the planning alternative. For this purpose, UPSS integrates two novel methods. These deal respectively with the ex post identification of relevant scenarios for the evaluation of the vulnerability and resilience of the alternatives, and with the assessment of relational uncertainty. According to the risks and opportunities borne by the system, the process makes it possible to select an infrastructure plan to alleviate the problem of urban vulnerability, as well as a set of relational contracts for its proper implementation across the different governmental scales of the infrastructure system. The whole process is tested via a case study, in which USPP first proposes optimal urban infrastructure plans that contribute to ameliorate the problem of urban vulnerability in Spain, then evaluates the risks and opportunities attached to the planning alternatives, and finally presents sets of policy measures to accompany the implementation of the alternative selected.

Keywords: Urban vulnerability; infrastructure planning; multi-scale; risk; opportunity; relational uncertainty.

5.1 Introduction

List of Abbreviations:

USP	Urban strategic planning
UVA	Urban vulnerability assessment
UIP	Urban infrastructure plans
PSS	Planning support system
DMs	Decision-maker
MOO	Multi-objective optimization
D-ROSE	Dynamic Risks and Opportunities Simultaneous Evaluation
MS-ReRO	Multi-Scale Relational Risks and Opportunities
SOW	States of the world
UVI	Urban vulnerability impact
AEI	Actions economic impact
EIEL	Survey of local infrastructure and equipment (Encuesta de infraestructura y equipamientos locales)

Both urban strategic planning (USP) and urban vulnerability assessment (UVA) demand comprehensive approaches that integrate methods to address key issues identified for an effective USP (Malekpour et al., 2015). These issues are connected with current UVA research by Salas and Yepes (2018a) (Table 5.1), who proposed a decision framework for selecting UVA models that fulfill these requirements (2018b), including the ability to monitor and anticipate vulnerability, which "would be a public good for all potentially affected places and systems" (Stern et al., 2013, p. 609).

Method	Characteristics							
	Multi-Criteria assess.	Strategic/Multi-Objective capacity	Partici-patory	Cogni-tive	Uncertainty-Scen. Analysis		Comprehen. Assessment	Multi-Scale
					Risk	Opport.		P-A (*)
UVAM method (**)	✓	✓	✓	✓	✓	✓	✓	✓
AST	✓		✓					✓
APST	✓		✓					
IPSS	✓		✓				✓	
UPSS (Method proposed)	✓	✓	✓	✓	✓	✓	✓	✓

(*) Political-Administrative
(**) Salas & Yepes 2018b

Table 5.1 Characteristics demanded for an effective urban strategic planning:

This ability can help to solve the resource-allocation problems faced by urban planning when dealing with urban vulnerability (UV) (King and Blackmore, 2013) by providing prioritization guidelines for its implementation (Nahiduzzaman et al., 2015). The European Union, for example, has allocated major resources to programs aiming to deal with UV, such as the URBAN I and URBAN II projects. These programs have together mobilized up to € 3.380 millions of total investment, spread across 188 urban projects (Table 5.2) selected from proposals submitted by 15 countries. This entailed a decision-making process, from the proposal of candidate projects for these programs to the selection of those that were finally awarded ERDF funds, in which different aspects of UV played a key role (Hurtado, 2012). In the case of Spain, however, the lack of a UVA method common to all candidates (Hurtado, 2012), the lack of a comprehensive approach enabling an understanding of the interrelated trends in UV (Hurtado, 2017), and the absence of a multi-scale assessment framework to provide an integrated evaluation of entities at the three relevant levels of government (Central Government, regions, and cities) (Hurtado, 2017), has led to failures in the allocation of the resources committed (Hurtado, 2012).

Program	Time Span	EU (*)			SPAIN (*)		
		Nº Urban programs	ERDF contribution (Mio €)	Total investment (Mio €)	Nº Urban programs	ERDF contribution (Mio €)	Total investment (Mio €)
URBAN I	1994-1999	118	900	1,800	30	152	235
URBAN II	2000-2006	70	728	1,580	10	120	260
Iniciativas Urbanas (**)	2007-2013	-	-	-	70	344	542
TOTAL	1994-2013	188	1,628	3,380	40	272	495

(*) Retrieved from European Union, Regional Policy. Ex-Post Evaluation of The URBAN Community Initiative 1994-1999 and 2000-2006
(**) Spanish program

Table 5.2 Investment on URBAN programs and ERDF support allocation

Planning support systems for urban vulnerability

Several previous efforts have been made to tackle the problem of UV through infrastructure planning (Table 5.1). AST was developed by Voskamp and Van de Ven (2015) as a planning support system () enabling collaborative planning that provided the users with site-specific sets of blue-green measures to handle flooding, drought and heat stress vulnerability for a particular urban reconstruction project, from which it was possible to assess a planning option across several scales. The APST method, in turn, was proposed by Van de Ven et al. (2016) to provide sets of adaptation measures, the effectiveness of which is evaluated in terms of drought control, heat stress reduction, quality of water and average costs of construction and management. Finally, investment decisions can be informed by means of the IPSS (Schweikert et al., 2014), a PSS providing a range of information including the construction, maintenance and adaptation costs of a comprehensive road infrastructure within an area, given several climate change scenarios.

All these methods, however, showed important shortcomings in the achievement of an effective USP. These included the lack of the strategic capacity required both to propose multi-objective optimal solutions, and to enable decision-makers to extract knowledge from the relations between the criteria used to assess urban infrastructure plans (UIPs) (Table 5.1). In addition, the frameworks analysed failed to assess infrastructure systems across the multiple political–administrative scales, and they were limited to evaluating scenarios without deriving any probabilities or impacts. This rendered them unsuitable for analysing alternatives in terms of the risks and opportunities attached to them (Table 5.1). While these issues have been addressed for UVA in previous work (Salas and Yepes, 2018b), a method for integrating them is still pending for generating UIPs to ameliorate the problem of UV.

Following the discursive approach previously employed for the generation and selection of UVA models (2018b), this paper overcomes the existing limitations by means of the Urban Planning Support System (UPSS), an integrative in which these issues are addressed by multi-objective optimization (MOO) for the generation of planning alternatives. By means of the D-ROSE method, the alternatives are then evaluated under a range of scenarios that have been found by decision-makers (DMs) to be relevant, in terms of risks and opportunities (Figure 5.1). Once a planning alternative has been selected, the analysts are able, through MS-ReRO, to determine the set of accompanying policy measures, in the form of relational contracts between the multiple governmental scales. This offers better prospects for proper implementation of the infrastructure plan selected across the multiple political–administrative layers of the system.

Scenario Analysis

Scenarios can be defined as the different states of the world (SOW) that may affect a decision's outcome, where the states of the world are represented by combinations of values that the set of exogenous variables can adopt (Kasprzyk et al., 2013). In contrast to ex ante approaches, in ex post methods (Table 5.3) the scenarios are generated parametrically or stochastically by varying the data of the exogenous variables. In this way, the analyst can observe how changes in these scenarios, i.e. in their policy assumptions, may affect the performance of their planning strategies, and identify scenarios ex post according to the risks or the opportunities that they present (Ray & Brown, 2015). Unlike other proposals (Table 5.3), in the Dynamic Risks and Opportunities Simultaneous Evaluation (D-ROSE) method, analysts are enabled to ex post delineate relevant scenarios by dynamically setting up the relevant (vulnerability and resilience) criteria, from where the risks and opportunities of the scenarios and alternatives are simultaneously evaluated (Figure 5.1).

Characteristics:		Info-	RDM	DAPP	Decision	D-	MS-
Scen. Identification	Failure(Worst)		✓	✓	✓	✓	✓
	Windfall(Best)	✓				✓	✓
Dynamics	Time			✓			
	P-A (*)					✓	✓
Multi-Scale	Time						
	P-A (*)					✓	✓
Relevant Scen.	Ex Ante		✓				
	Ex Post					✓	✓
Scen. Trade-offs	Vars/Scen		✓		✓		
	Alt/Scen	✓				✓	
	Risk/Opp					✓	
	Multi-Obj		✓			✓	
Policy Actions				✓			✓

(*) Political-Administrative

(**) Ranges of scenario values triggering vulnerabilityes

Table 5.3 Characteristics of Bottom-Up Decision support Systems

Multi-scale dimension of infrastructure systems: problem and solution
Infrastructure systems are spatially and functionally interdependent multi-scale hierarchical systems (Johansson & Hassel, 2010) where entities are affected by sub-entities, which enable bottom-up cascade-failure (Eusgeld et al., 2011). Infrastructure planning, in consequence, is affected by this multi-level and complex nature (Frank & Martínez-Vázquez, 2015), should consider inter-scale relationships in methods attempting to evaluate uncertainty (Sierra et al., 2017), and capture system's ability to adapt to failures of sub-entities (Eusgeld et al., 2011). Several policy options have been defined to address this challenge, all of which pursue the improvement of the overall performance (Charbit & Michalun, 2009). However, there is a lack of integral infrastructure planning and investment strategies that take overall performance into account (Charbit & Gamper, 2015) and measure impacts at the overall (system-of-systems) scale (Eusgeld et al., 2011), which has led to failures of co-ordination among scales that need to be mitigated (Frank & Martínez-Vázquez, 2015).

The method presented aims to bridge this gap by means of a relational system that implements relational contracts between governmental scales. In the Multi-Scale Relational Risks and Opportunities (MS-ReRO) scenario module (Figure 5.1), the behaviour of infrastructure plans is evaluated across the range of possible configurations of relational contracts (Frank & Martínez-Vázquez, 2015), and optimal policy strategies are proposed to minimize the risks while maximizing the opportunities associated with inter-scale coordination.

The remainder of this paper is organized as follows. In the methods section, the planning process framework is described and the framework's theoretical foundations are explained in detail. In the case study section, the methods presented are illustrated by an exercise in which the methodology proposed is applied to an actual case, and the results are presented in the subsequent section. The method is then analysed and compared in the discussion section to show its efficacy. Finally, general conclusions are drawn in the closing section.

5.2 Methods
This section describes the whole process, analysing its elements one by one as indicated in Figure 5.1. First is a description of how the process works in general; then, for each step, detailed explanations are given.

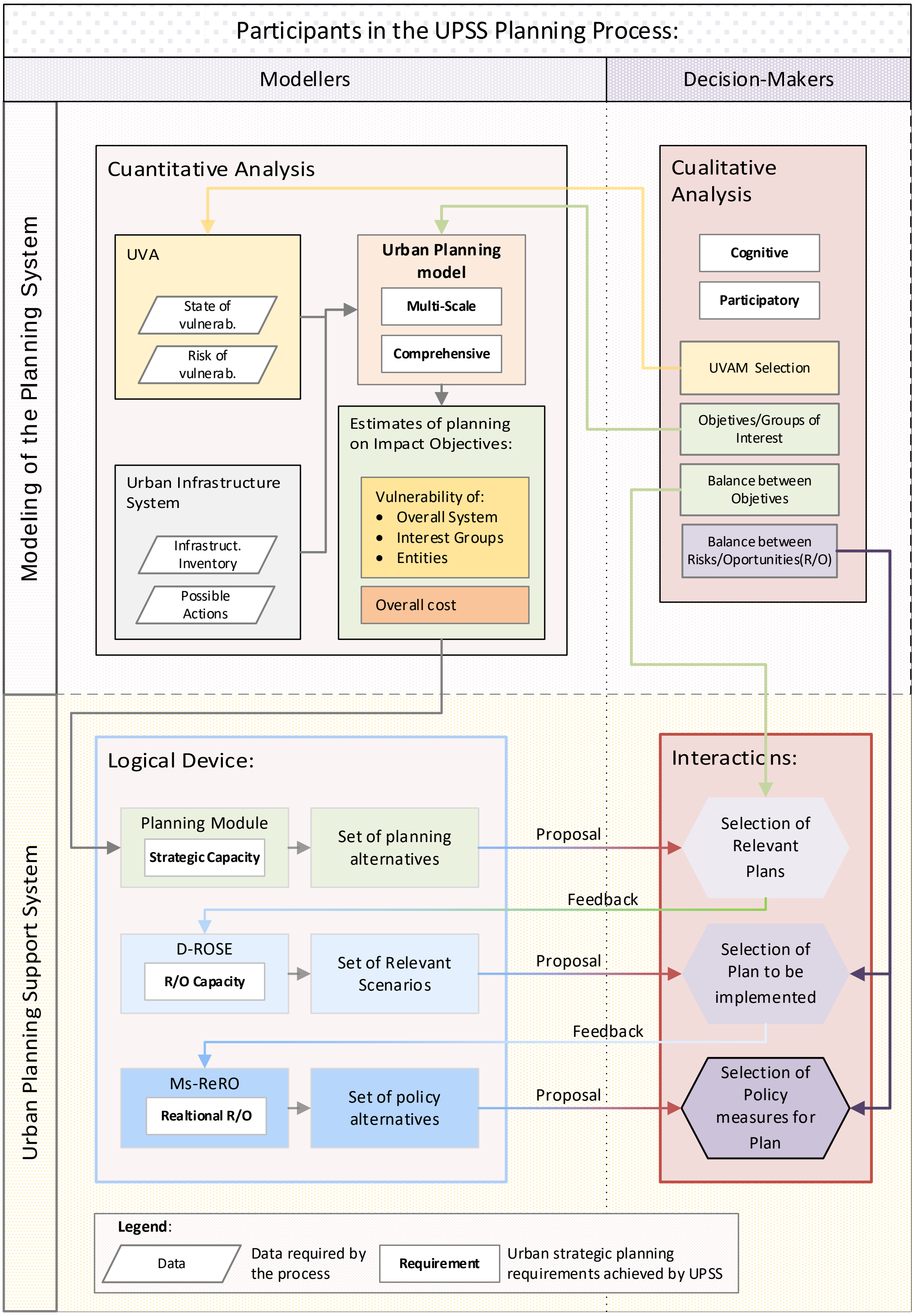


Figure 5.1 Overall workflow and USP requirements achieved by the urban planning support system

5.2.1. General Workflow

The idea is to elicit general guidelines by following a three-step process. In the first step, once the process set-up has been performed (Figure 5.2, I-0), a set of Pareto-optimal models (Figure 5.2, S-1) is elicited through the Planning Module (Figure 5.2, PM), and analysed (Figure 5.2, G-1). In the second step, a set of future SOWs generated by the D-ROSE module (Figure 5.2, SM-I) is analysed (Figure 5.2, G-2) in order to obtain relevant scenarios (Figure 5.2, S-2) and choose a planning alternative (Figure 5.2, I-2). As the third step, the MS-ReRO module is run upon the planning alternative selected, to produce policy measures to alleviate eventual problems arising from multi-scale relational uncertainty, and allowing knowledge to be generated (Figure 5.2, G-3) to inform the selection (Figure 5.2, I-3) of the proper policy measures to accompany the infrastructure plan previously chosen.

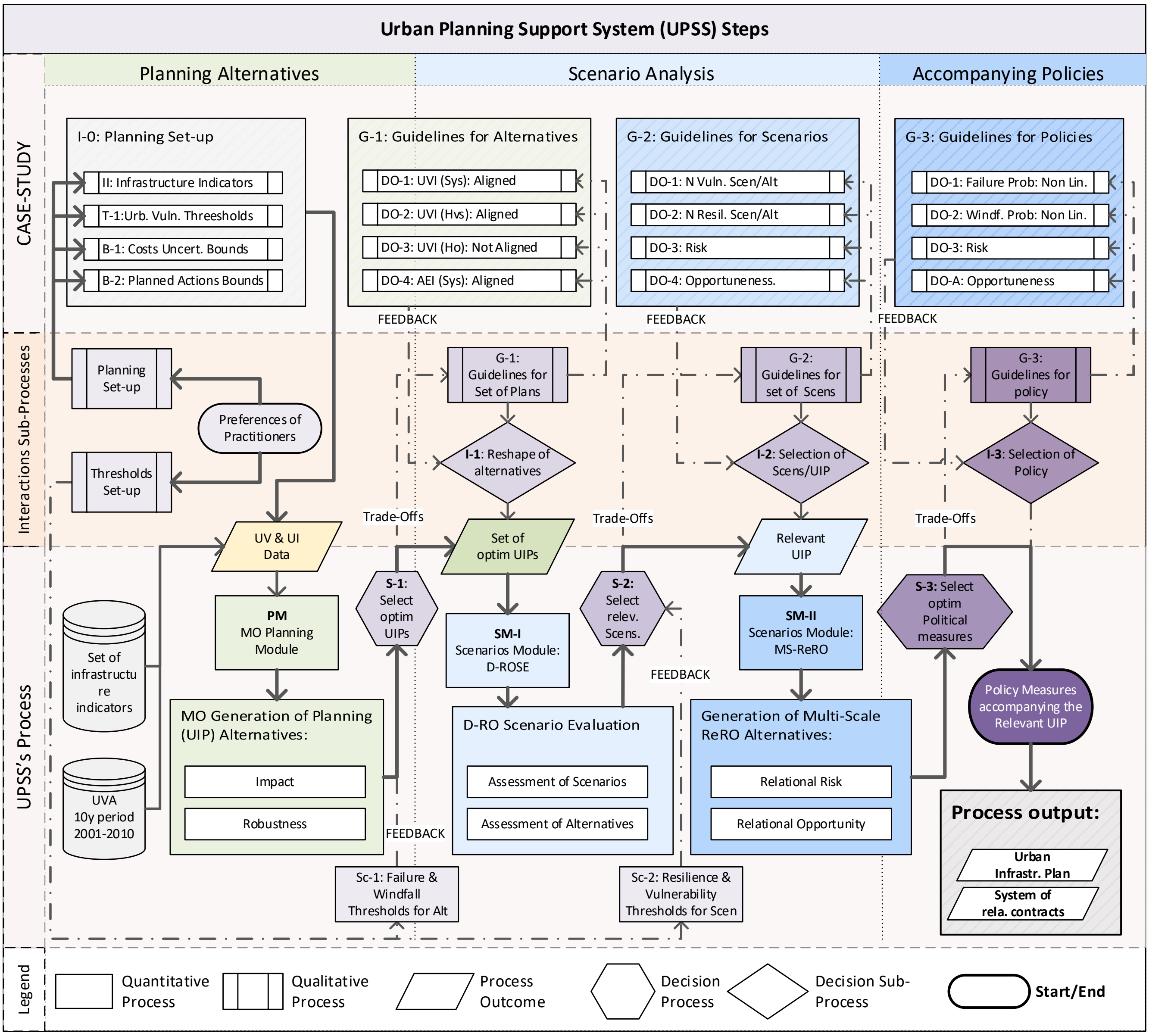


Figure 5.2 Detailed workflow of the planning system and case study

5.2.2. Planning module: Generation of Planning (Figure 5.2, PM)

The generation of planning alternatives was addressed via formulation of a MOO model (Salas & Yepes, 2018b), in which the decision criteria were implemented as the objectives that the optimization model sought to achieve (Kasprzyk et al., 2013). The framework presented improves the effectiveness of other planning methods also providing sets of possible solutions (APST), by proposing only Pareto-optimal solutions, thus preventing the adoption of less effective, non-relevant alternatives. This feature allows trade-offs to be made between objectives, which can be used as guidelines for the selection of relevant and always optimal planning alternatives, giving the decisional system the strategic capacity (Figure 5.1) demanded by current strategic planning that other methods lack (Table 5.1).

5.2.2.1. Definition of impact objectives

By means of the impact objectives, the effects of solutions (Figure 5.2) on the system's urban vulnerability are described and encoded as criteria for selecting alternatives.

Urban vulnerability impact

Having selected in the process set-up (Figure 5.2, I-0) an urban vulnerability assessment (UVA) model, its results were employed to build up statistical models that relate the evolution of infrastructures with the evolution of urban vulnerability. Due to the complex, multi-scale character of urban vulnerability (Adger, 2006), the correlation between its evolution and that of the infrastructure equipment was studied across all the scales present in the UVA model, and specific step-wise multi-variate linear regression models were fitted for each scale to estimate the impact of infrastructure-related variables (Mejia Dorantes et al., 2011). In our case, UV evolutions of each entity were treated as the responses observed, and the evolutions of each type of infrastructure considered were regarded as predictors, enabling the model to assess the impact of changes of the infrastructure equipment on the evolution of UV.

From infrastructure actions to impact changes:

Changes in the infrastructure indicators need actions, implemented though infrastructure planning, to be operated. If there were, for example, a need to change a road's state from poor to good, it would need concrete actions, comprised within the roads rehabilitation category, such as pavement milling and structural resurfacing (Yepes et al., 2016). Following this logic, a device was built relating actions with the explanatory variables accepted by the predictive model (Table 5.4). By means of this, the model was allowed to transpose infrastructure planning into positive impacts on urban vulnerability, which thus became available as an objective for the generation of planning alternatives.

Infrastructure/Explanatory Vars:			Actions Vars:				
Description	Id	Unit	Type	Treatment	SLI	Treat/period	Period
Net Infrastructures:							
Roads:							
Road State Good	1	m2	Preservation	1.02	3	4	4
Road State Poor	2	m2	Rehabilitation	66.74	25	1	67
Road State Execution	3	m2	Construction				
Road State Fair	4	m2	Maintenance	23.24	10	1	23
Roads State Total	26	m2	Build	496	25	1	496

Infrastructure/Explanatory Vars:			Actions Vars:				
Description	Id	Unit	Type	Treatment	SLI	Treat/period	Period
Road Ownship Province	5	m2	Transference				
Road Ownship Region	6	m2	Transference				
Road Ownship Central	7	m2	Transference				
Road Ownship Other	8	m2	Transference				
Roads Ownship Total	27	m2					
Point Infrastructures:							
Land:							
Land Use Urban	9	m2	Liberalize				
Land Use Rural	10	m2	Protect				
Land Use Rural_preser	11	m2	Protect				
Land Use Total	28	m2	Change				
Health Centers:							
Health State Good	12	m2 built	Preservation	15	1	10	150
Health State Poor	13	m2 built	Rehabilitation	374	25	1	374
Health State Execution	14	m2 built	Construction				
Health State Fair	15	m2 built	Maintenance	74.8	5	2	150
Health Total	29	m2 built	Build	748	50	1	748
Educational Centers:							
Educational State Good	16	m2 built	Preservation	10	1	10	100
Educational State Poor	17	m2 built	Rehabilitation	408.5	25	1	409
Educational State Execution	18	m2 built	Construction				
Educational State Fair	19	m2 built	Maintenance	81.7	5	2	163
Educational Total	30	m2 built	Build	0	25	1	0
Parks:							
Park State Good	20	m2	Preservation	6	1	10	60
Park State Poor	21	m2	Rehabilitation	12.5	25	1	13
Park State Execution	22	m2	Construction				
Park State Fair	23	m2	Maintenance	2.5	5	2	5
Park Total	31	m2	Build	25	25	1	25
Garbage:							
Garbage Perform. Adequate	24	mun	Preservation	15	1	10	150
Garbage Perform. Inadequate	25	mun	Rehabilitation	0	1	10	0
Garbage Capacity Total	32	tn	Build				

(*) Service Life Increase
(**) Number of treatments required along the period being considered

Table 5.4 Infrastructure variables and planning actions

Economic impact:

Along with the impact on the evolution of UV, actions were evaluated in terms of their economic impact by means of assigning costs to actions, and two types of impacts were thus obtained for each entity, namely the urban vulnerability impact (UVI), and the actions economic impact (AEI), whose overall formulation is as follows:

$$UVI_{Sys} = \sum_{i,j} UVI(Plan_j, Mod_i) \tag{5.10}$$

$$AEI_{Sys} = \sum_{i,j,k} Action_{(i,j,k)} \times ICost_{(i,j,k)} \times IcostAsymm_{(i,j)} \tag{5.2}$$

where UVI_{Sys} and AEI_{Sys} are respectively the UV and the overall economic impacts of the Sys system, i is each of the system's hierarchical scales, j is each of the entities in i scale, k is each of the actions planned for the j entity, UVI is the evaluation of the $Plan$ set of actions planned for each j entity under the Mod regression model assigned to each i scale, $Action$ and $ICost$ are, respectively, the quantification of actions and unitary costs of each k action, and $IcostAsymm$ is the normalized asymmetry index (Table 5.5).

Region		Normalyzed Asymmetry Index (*)	Accompanying Policy			
			Config of IGRCs (**)		ReRO Inter-Scale Assessment	
ID	Name		Righ	Dutie	Risk	Opportunity
0	Nacional	1			6,24E+06	5,17E+06
1	Andalucía	0.895	12		0	1,14E+07
2	Aragón	1.1826	12		5,16E+05	0
3	Asturias	1.002	16		1,45E+03	0,00E+00
4	Balears	0.9008	16		0	1,69E+06
5	Canarias	0.9295	15		0	0
6	Cantabria	1.0407	15		4,48E+05	0
7	Castilla y León	1.0467	15		3,71E+06	0
8	Castilla - La	1.0286	13		4,91E+07	0
9	Cataluña	1.1041	16		1,07E+05	0
10	Comunitat Valenciana	0.98	15	3	3,19E+05	1,36E+05
11	Extremadura	0.9325	14		0	0
12	Galicia	0.9381	15		0	1,25E+06
13	Madrid	1.0072	15		8,29E+03	4,93E-01
14	Murcia	0.9463	15		5,40E+00	1,30E+04
15	Navarra	1.214	14		2,16E+05	0
16	País Vasco	1.1138	15		8,83E+06	0
17	Rioja, La	1.1526	14		3,34E+03	0
18	Ceuta	0.8947	15		0	0
19	Melilla	0.8537	15		0	170881,6407
20	Provinces(***)	By region	10	0,025	3,91E+07	3,73E+05
21	Cities (***)	By province	12	0,015	3,69E+04	1,93E+04

(*) Extracted from costs of housings, Index by regions (Spanish INE)
(**) Inter-Governmental Relational Contracts
(*** Mean of values

Table 5.5 Asymmetry index and process results by regions

5.2.2.2. Definition of groups of interest

When coping with urban vulnerability, specific attention should be paid to the most vulnerable entities (Adger, 2006). In consequence, a metric was added in order to enable DMs to account for the relative differences in the impact of each planning alternative on the group of the most vulnerable, i.e., to take equity into account (Sierra et al., 2018a). As a result, a high vulnerability state threshold ($HVST$) was generated to select, for each scale, the group of the highest vulnerability state (Hvs) entities as those beyond that limit. This allowed the elicitation of the UVI_{Hvs} and AEI_{Hvs} metrics, obtained in an analogous way to the UVI_{Sys} and AEI_{Sys} but accounting only for those entities included in the Hv group:

$$Hvs = (Hvs_1, \dots, Hvs_i): Hvs_i = (ent_{i1}, ent_{i2}, \dots, ent_{ij})\ \forall\ ent_{ij} \mid StateRank_i(ent_{ij}) > HVST_i \quad (5.3)$$

where Hvs_i is the group of the j entities at i scale whose position in the $StateRank_i$ is above the $HVST_i$ threshold.

In a similar vein, it would also be of interest for decision-makers to know the impacts on entities presenting the best opportunities to improve their state of vulnerability (SV) in the future, understood as the situation in which entities present a low state of vulnerability and a high chance of becoming less vulnerable (Salas & Yepes, 2018b). Conversely to the criterion required to become a member of the Hvs group, for being a member of the low vulnerability state group (Lvs), the condition was to have a $StateRank$ below the low vulnerability state threshold ($LVST$). In addition to this requirement, members of the high opportunity group (Ho) were also required to have a risk of vulnerability below the low vulnerability risk threshold (LRT), and therefore the rule to become a member of the high opportunity group was formulated as follows:

$$Ho = (Ho_1, \dots, Ho_i): Ho_i = (ent_{i1}, \dots, ent_{ij})\ \forall\ ent_{ij} \mid StateRank_i(ent_{ij}) < LST_i\ \wedge\ RiskRank_i(ent_{ij}) < LRT_i \quad (5.4)$$

where Ho_i is the group of the j entities at i scale whose position in the $RiskRank_i$ is below the LRT_i threshold, while its position in the $StateRank_i$ is below the LST_i threshold.

Based on the above, the UVI_{Hvs}, AEI_{Hvs}, UVI_{Ho} and AEI_{Ho} metrics were obtained in an analogous way to those for the whole system (UVI_{Sys} and AEI_{Sys}) but limiting to entities included in the Hvs or in the Ho group. In consequence, the proposed planning framework can effectively represent the consequences of infrastructure plans for specific groups of interests, such as those more vulnerable, promoting stakeholders engagement and improving the participatory capability of the whole method by enabling participants to appreciate the returns that each planning alternative may have for them.

5.2.2.3. Definition of robustness objective

Monte Carlo simulation is recognized as an appropriate method for uncertainty analysis and has been previously used to incorporate uncertainties into optimization models (Liao et al., 2011). Broadly speaking, this method analyses how a model's outcome behaves when the inputs vary from their expected values following a given probability distribution. Once Monte Carlo simulation has been performed, the robustness of the model can be evaluated by assessing, for each k input variable, the relative size of its variance v with respect to its mean m, and then aggregating these ratios, obtained for the n variables composing the model, to assess its overall robustness Rob_{Sys} (Salas & Yepes, 2018b):

$$Rob_{Sys} = 1 \Big/ \left(\sum_{k=1}^{n} \left(\frac{v_k}{m_k}\right)\right) \quad (5.5)$$

where models with small variance in comparison with the mean are robust (Hermeling et al., 2013).

Table 5.6 portrays all the objectives considered in the multi-objective configuration (column B), which can be formulated as:

$$minimize\ F\ (x) = \left(f_1(x), \dots, f_{obj}(x)\right)T \qquad (5.6)$$

$$s.t.\ x\ \in\ \Omega, \forall\ x \leq LastP \times \left(1 + \mathrm{PA_{Scope}}\right)\ \wedge\ x \geq \max(LastP \times \left(1 - \mathrm{PA_{Scope}}\right), LastP \times (1 - \mathrm{PA_{Lb}}))\ ,$$

where Ω is the decision space, $LastP$ is the last plan carried out, $\mathrm{PA_{Scope}}$ is the range of possible values around $LastP$, $\mathrm{PA_{Lb}}$ is the minimum actions to be carried out in the current plan, $x \epsilon \Omega$ is a decision vector and obj is the objective function according to Table 5.6.

Variables:								
Item	Description	Equ.	1: MO Gen.of Altternatives		2: D-ROSE		3: MsReRO	
			Type	Value (**)	Type	Value (**)	Type	Value (**)
Planning Module:								
Alternative								
UIP	Urban Infrastructure Plan coping with UV	5.6	Decision Variable		BaseLine Data		Parameter	
Set-up of Alternatives:								
PA_Scope	Range of Possible Actions (from previous	5.6	Optimization	0.15				
PA_Lb	Max.percent of unnatended actions from	5.6	Param	0.25				
Objectives (Assessment of Alternatives):								
UVI(Sys)	Impact on Sytem's Urban Vulnerability	5.1	Optimization	-8.60E+7	BaseLine	-2.68E+03	BaseLine	
UVI(Hvs)	Impact on Highly vulnerable entities' UV	5.2	Objective,	-2.27E+6	Data	-1.22E+08	Data	
UVI(Ho)	Impact on High opp. entities' UV	5.3	Criteria for	-6.27E+7		-2.56E+06		
AEI(Sys)	System's costs of all infrastructure projects	5.3	selecting a set	all		2.04E+08		
AEI(Hvs)	Economic Impact on Highly vulnerable	5.4	of relevant	all		2.86E+06		
AEI(Ho)	Economic Impact on High opp. Entities	5.4	alternatives	all		3.15E+07		
Rob(Sys)	Sys's Robustness against economic costs'	5.5	(fig 5.2, S-1; vid 1)	all		22.2896		
Set-up of Impact Objectives:								
HVST	High vulnerability state threshold (most	5.3	Objectives'	[30,30,30]	BaseLine		BaseLine	
LVST	Low vulnerability state threshold (less	5.4	set-up	[30,30,30]	Data		Data	
LRT	Low Risk Threshold (less risk)	5.4	parameters	[30,30,30]				
Icost	Infrastructures costs by activities	5.2	BaseLine Data	Table 5.1				
ICostAsy	Infrastructure costs Asymmetry Index	5.2		Table 5.5				
Set-up of Construction Costs' uncertainties (Robust. Obj.):								
CC_Lb	Lower bound (% from baseline)		MC	0.2	Baseline		Baseline	
CC_Ub	Upper bound (% from baseline)		Simulation ex	0.15	Parameter		Parameter	
Scenarios Module:								

Variables:									
Item	Description	Equ.	1: MO Gen.of Altternatives		2: D-ROSE			3: MsReRO	
			Type	Value (**)	Type	Value (**)		Type	Value (**)
BaseLine Relational Contracts:									
Rights	Rights that are transferred	5.7			Scen BaseLine	[0.3;0.2;0.2			
Duties	Duties that are commited					[3;2.5;1.5]			
Scenario Metrics (Assessment of Scenarios/Alternatives):									
N(Alt_Vul	Number of vulnerable alternatives per	5.22			Criteria for choosing relevant scen (fig 5.1, S-2; vid 5.2)	5.2			
N(Alt_Res	Number of resilient alternatives per scenario	5.23				0.84			
ScenR	Scenario Risk	5.19							
ScenO	Scenario Opportunity	5.20							
N(Scen_V	Number of relevant vulnerable scenarios	5.17			Criteria for choosing UIP (fig 5.1, I-2; vid 5.2)	7			
N(Scen_R	Number of relevant resilient scenarios	5.18				3			
AltR	Alternative Risk	5.24				1.83E+06			
AltO	Alternative Opportunity	5.25				6.07E+05			
TotFail	Total Failure probability	5.26							18.75%
TotWindF	Total Windfall probability	5.27							18.75%
ReFail	Relational Failure probability	5.11							12.71%
ReWindF	Relational Windfall probability	5.16							6.06%
ReRisk	Relational Risk	5.13							4.45E+06
ReOpp	Relational Opportunity	5.16							2.32E+06
Set up of Scenario Metrics:									
TF	Threeshold for Failure (% cost increase from	7			U. Metrics ex ante param. (fig 5.2, Sc-1)	(+) 0.01	Scen ex ante para	(+) 0.01	
TE	Threeshold for Exploitation (% cost decrease from baseline)	7				(-) 0.01		(-) 0.01	

Variables:								
Item	Description	Equ.	1: MO Gen.of Altternatives		2: D-ROSE		3: MsReRO	
			Type	Value (**)	Type	Value (**)	Type	Value (**)
Set-up of Scenarios' Uncertainties:								
Rights_Ub	Upper bound for rights (from Scen baseline				MC simulation	0.15	Optimization	0.15
Rights_Lb	Lower bound for rights (from Scenbaseline					0.5		0.5
TVul	Threeshold of vulnerability (min required)	5.21			Scen ex post	5.2		
TRes	Threeshold of resilience (min required)	5.21				1.27		
(*)	Scales are regions, provinces and cities							
(**)	In bold, values corresponding to the UIP resulting from the decisional							

Table 5.6 Problem formulation, variables and framework results

5.2.3. Scenarios module, discovering scenarios and proposing policy measures (Figure 5.2, SM-I & SM-II)

5.2.3.1. Co-ordination policy options into a decision-making framework

With regard to the decision-making process, articulating a contract among the scales coordination policy option into a complex, multi-scale infrastructure system entails the transfer of both attributions and responsibilities from upper to lower hierarchical scales. In other words, this decision-making process follows a top-down sequence, in which the coordination between scales is shaped by a relational contract. However, there is no specific best relational contract to be applied in general. On the contrary, the best solution depends upon the nature of the problem and upon the institutional context in which the contract takes place (OECD, 2007), and it takes form as a particular setting of mutual rights and duties between scales (Frank & Martínez-Vázquez, 2015). Besides, since the institutional context is in turn dependent on the entity considered within a given scale, a systemic approach for determining an appropriate governmental contract among scales should consider both vertical and horizontal asymmetries among scales and among elements of the same scale respectively (Frank & Martínez-Vázquez, 2015).

5.2.3.2. Multi-Scale Relational Risk and Opportunity (MS-ReRO) assessment of hierarchical multi-scale systems

- *Co-ordination policy options: finding the best model*

To represent multi-scale government contracts, two sets of variables representing the rights and duties transferred between parties (Charbit & Michalun, 2009) were considered. Rights were modelled as the range in which sub-entities can choose actions alternative to the baseline of their upper entity, which means they were treated as variables. Duties, in turn, represented the common objectives agreed in the contract, to the fulfilment of which the parties must be committed (Frank & Martínez-Vázquez, 2015), and they were therefore a constraint, outside which the contract was considered to fail. As a consequence, for any entity whose performance relies upon that of a set of sub-entities, a governmental contract between them can be defined as a function of the thresholds of choice allowed (rights), and of the performance demanded from each sub-entity (duties) to attain the common objectives agreed.

Since, in a multi-scale system, entities depend for their performance on other sub-entities in the lower scale to which rights and duties are transferred, there is a risk of failure for the former, induced by the behaviour of those sub-entities on which it depends (Figure 5.2). From the perspective of the overall (baseline) performance, governmental contracts are mechanisms for transferring the decision-making capacity (rights) across scales, entailing a certain risk of failure that is propagated across scales as a bottom-up effect (Figure 5.2). In such a system, entities may fail due to the behaviour of their sub-entities, where failure is understood as the lack of fulfilment of the entity's duties. Conversely to this risk, the opportunity reflects the probability and the impact of achieving a better performance than expected (windfall) due to the action of the sub-entities, which are assumed to have a better knowledge of the local circumstances that can be translated into, for example, minimizing costs (Frank & Martínez-Vázquez, 2015).

This implies that finding the best policy alternative for setting up inter-scale contracts needs to balance the pros (opportunities) and cons (risks) entailed by every policy alternative. These are defined by the choice (right) and the performance (duty) thresholds attached to each contract. The Multi-Scale Relational Risks and Opportunities (MS-ReRO) method proposed in this paper aims to contribute to the above by providing policy alternatives that offer compromise solutions attending to risks and opportunities.

- **Modelling a system of relational contracts**

As pointed out by Eusgeld et al. (2011), risk assessment of the relational contracts system overall performance should consider the probability of a relational failure induced by the failure of sub-entities across all scales, which can be modelled as a failure tree (Figure 3). Failure (F) is defined as the state S in which the $AEI_{\ i,j}$ economic evaluation of entity (i,j) (section 5.2.2.1) is below a given Threshold of Failure (TF). Conversely, Windfall (W) is defined as the state S in which $AEI_{i,j}$ is above a given Threshold of Windfall (TW):

$$S_{i,j} = Fail \Leftrightarrow \quad AEI_{\ i,j} \quad < TF\ ;\ S_{i,j} = Windfall \Leftrightarrow \ AEI_{\ i,j} < TW \qquad (5.7)$$

The probability of this failure being caused by the sub-entities' lack of commitment to a relational contract with R rights (Figure 3) could be assessed, for each entity, as the posterior probability of failure of that entity given the failure of any of its sub-entities deviated $r \epsilon$ R from the base overall planning:

$$P\ (F^{R}{}_{i,j}) = \frac{N(F_{\ i,j})}{N(AEI_{\ i,j,r})} \qquad (5.8a)$$

$$P\left(F_{\ i,j} \middle| Fs^{R}{}_{i,j}\ \right) = \frac{N(F_{\ i,j}Fs^{R}{}_{i,j})}{N(F_{\ i,j})} \qquad (5.8b)$$

where P is the probability of the failure event, $F^{r}{}_{i,j}$ refers to failure of the entity i,j, $Fs^{r}{}_{i,j}$ refers to the failure of any of the sub-entities on which the entity depends, and N refers to the number of times that an event was observed.

Therefore, the probability of a relational failure induced on the entity by the failure of its sub-entities $P(F_{\ i,j}Fs^{R}{}_{i,j})$ was formulated using the law of total probability as:

$$P(F_{\ i,j}Fs^{R}{}_{i,j}) = P\left(F_{\ i,j} \middle| Fs^{R}{}_{i,j}\ \right)\ \times \sum_{s=1}^{nS} P(Fs^{R}{}_{i,j}Fss^{sR}{}_{i,j}) \qquad (5.9)$$

where$(Fs^{sR}{}_{i,j}Fss^{sR}{}_{i,j})$ is the probability of failure of any of the sub-entities "s" to which entity i,j is attached, given the failure, under a sub-contract with rights sr, of any of the "ss" sub-sub-entities to which the sub-entities are in turn attached:

$$P(Fs^{R}{}_{i,j}Fss^{sR}{}_{i,j})\ =\ P\left(Fs^{R}{}_{i,j}\ \middle| Fss^{sR}{}_{i,j}\right) \times\ \sum_{ss=1}^{nSS}\ P(Fss^{sR}{}_{i,j}\ ) \qquad (5.11)$$

where $P\left(Fs^{R}{}_{i,j}\ \middle| Fss^{sR}{}_{i,j}\right)$ is the conditional probability of failure of the s given the failure of any SS of its nSS sub-sub-entities, and $P(Fss^{sR}{}_{i,j}\ )$ is the probability of this failure.

For the elicitation of probabilities, the method employed a Monte Carlo simulation-based approach, which has been previously used to deal with complex-system failure problems (Nguyen et al., 2015). This technique evaluates the system through a large number of scenarios, stochastically generated following their pdf. Since the aim was to identify the impact on the performance of entities produced by the actions of sub-entities, this latter was modelled by means of a triangular distribution function whose extreme values were the upper and lower bounds defining the rights endowed by the government contract between the entity and sub-entities (Figure 3). Likewise we selected, as the triangular functions' peak values, those of the actions under the baseline plan, which represents the contract duties (contribution to the overall objective) arranged between the parties.

On this basis, the probability of the system's failure due to the rights and duties bestowed upon its sub-entities through relational contracts was calculated following a bottom-up process, which begins with the probabilities of entities in the basic (lowest) scale, and propagates across the scale until the last (system) level (Figure 3). In the lowest scale, the conditional probability and total probability are equal, due to the fact that the entity and the sub-entity are the same.
Given that

$$P\left(Fs^{R}{}_{1,j}\,\middle|Fss^{sR}{}_{1,j}\right) = P(Fs^{R}{}_{1,j}) \quad (5.1112)$$

And following the criteria employed in UVA assessment (Salas & Yepes, 2018b), the relational risk was modelled as the product of probability and impact (Dessai and Hulme, 2004):

$$ReRisk(F_{Sys}) = \prod_{i,j}^{nScales-1}\left(P(F_{\ i,j}Fs^{R}{}_{i,j}) \times \sum_{j}^{nEnt} P(Fs^{sR}{}_{i,j}Fss^{sR}{}_{i,j}) \times FI_{i,j}\right) \quad (5.12)$$

where $FI_{i,j}$ is the impact on the performance of the entity "i,j" produced by the failure event $\left(F_{\ i,j}\middle|Fs^{R}{}_{i,j}\right)$:

$$FI_{i,j} = AEI^{\ BL}{}_{i,j} - \overline{AEI^{\ F}{}_{i,j}} \quad (5.13)$$

where $AEI^{\ BL}{}_{i,j}$ is the baseline performance expected to be attained by the entity i,j, and $\overline{AEI^{\ F}{}_{i,j}}$ is the mean performance value of the failure events observed for that entity (Lempert et al., 2006).

Taking the values of the best cases, the windfall impact was formulated conversely to that of risk, as

$$WI_{i,j} = AEI^{\ BL}{}_{i,j} - \overline{AEI^{\ W}{}_{i,j}} \quad (5.134)$$

where $\overline{\overline{AEI^{\ W}{}_{i,j}}}$ is the mean performance value of the windfall events. As in the case of risk, opportunity was calculated in terms of the probabilities of the occurrence of windfalls due to the action of sub-entities:

$$ReOpp(W_{Sys}) = \prod_{i,j}^{nScales-1}\Big(P(W_{\ i,j}Ws^{R}{}_{i,j}) \times \sum_{j}^{nEnt} P(Ws^{sR}{}_{i,j}Wss^{sR}{}_{i,j}) \times WI_{i,j}\Big) \quad (5.15)$$

where $P(W_{\ i,j}Ws^{R}{}_{i,j})$ is the product of the probability of the sub-entities' windfall and the posterior probability of the entity having windfalls, given the windfall of any of the sub-entities.

The above resulted in a system of relational contracts represented by rights and duties between governmental scales, allowing to determine and balance the risks and opportunities attached to them.

5.2.3.3. Dynamic Risk and Opportunity Simultaneous Evaluation (D-ROSE) method

In relation with the overall problem formulation, these bounds, defining the rights assigned to sub-entities, acted as the exogenous factors (section 5.2.3.1, Scenario Analysis) constituting the policy scenarios affecting the behaviour of the infrastructure plans, which thus had to be assessed. This evaluation, carried out through Monte Carlo simulation, rendered the risks and opportunities that a given infrastructure plan conveyed across the range of scenarios (systems of governmental contracts) available, from where methods such as RDM provide the identification of vulnerable scenarios as those in which the alternatives (infrastructure plan) perform poorly (Kasprzyk et al., 2013). This performance was considered to be poor when it violated the vulnerability threshold, previously set up in accordance with the stakeholders' preferences. In our case, this threshold defines a minimum level of performance required, below which scenarios were regarded as more or less vulnerable. Besides, D-ROSE also seeks more resilient scenarios, which are identified as those in which more alternatives performed better than the windfall threshold, also as defined by the stakeholders. Therefore, the scenarios' vulnerability and resilience are defined as follows:

$$SV_{Scen} = N(Alt\,) \mid f(Alt) < TF \qquad (5.14)$$

$$SR_{Scen} = N(Alt\,) \mid f(Alt) > TW \qquad (5.17)$$

where SV_{Scen} and SR_{Scen} are the vulnerability and resilience of the "$Scen$" scenario, Alt are the alternatives, f is the fitness of each alternative, and TF and TW are the failure and windfall thresholds respectively.

We also assessed the scenarios' risks and opportunities as the product of the probability of being a vulnerable scenario, and the impact of such case:

$$ScenRisk_{scn} \;=\; P(SV_{scn}) \times I(SV_{scn}) \qquad (5.18)$$

where $ScenRisk_{scn}$ is the risk inherent to scenario "scn" provided a probability of occurrence $P(SV_{scn}) = \left({SV_{scn}}/{N(Alt\,)}\right)$, and an impact $I(SV_{Scen}) = f^{b}{}_{Scen} - \overline{f^{SV}{}_{Scen}}$, where $f^{b}{}_{Scen}$ is the performance of the baseline alternative, and $\overline{f^{SV}{}_{Scen}}$ is the mean performance of those alternatives being vulnerable in this scenario.

Conversely, the opportunity inherent to "$Scen$" ($ScenOpp_{scn}$) was defined as follows:

$$ScenOpp_{Scen} = \;P(SR_{scn}) \times I(SR_{scn}) \qquad (5.19)$$

where $P(ScenRes_{Scen}) = \left({SR_{scn}}/{N(Alt\,)}\right)$ is the probability of occurrence, and an impact $I(SR_{scn}) = f^{b}{}_{Scen} - \overline{f^{SR}{}_{Scen}}$, where $\overline{f^{SR}{}_{Scen}}$ is the mean performance of the alternatives being resilient in this scenario.

Based on the above, the decision-makers selected the relevant scenarios ($Relevant_{Scen}$) as those with the most interesting levels of vulnerability and resilience:

$$Relevant_{Scens} \;= (Scen_1, \dots, Scen_{scn}) \mid SV_{scn} \;< TVul \;\cap\; SR_{sen} \;> TRes \qquad (5.20)$$

where $TVul$ and $TRes$ are respectively the vulnerability and resilience thresholds. D-ROSE in the only method making use of both vulnerability and resilience thresholds, which are dynamically settled ex post, to select relevant scenarios for its further employment, allowing the DM to profit from the knowledge provided by the initial set of scenarios.

As a subsequent step, D-ROSE identifies those infrastructure plans that perform better against vulnerable scenarios and enables DMs to choose, from among them, the one with the most appropriate trade-off between vulnerability and resilience. We defined the alternatives' vulnerability and resilience against scenarios ($AV\ , AR$) as the number of scenarios in which they had a vulnerable or resilient performance:

$$AV_{alt} = N\left(SV_{scn} \in Relevant_{Scens}\right) \tag{5.21}$$

$$AR_{alt} = N\left(SR_{scn} \in Relevant_{Scens}\right) \tag{5.22}$$

In a similar vein to the case of the scenarios described above, the risk and opportunities inherent to each alternative under the relevant scenarios were formulated as the product of the probability of occurrence and its impact:

$$AltRisk_{alt} = P(AV_{alt}) \times I(AV_{alt}) \tag{5.23}$$

$$AltOpp_{alt} = P(AR_{alt}) \times I(AR_{alt}) \tag{5.24}$$

5.2.3.4. Proposing accompanying policies

As the final step of the scenarios module, the framework aimed to bridge the gap of proposing policy alternatives that ameliorate vulnerabilities (Kasprzyk et al., 2013) while maximizing opportunities (Frank & Martínez-Vázquez, 2015). For this purpose, a MOO problem was posed in which the thresholds of choice of each entity were the decision variables, and risks and opportunities were objectives to be respectively minimized and maximized (Table 5.6).

Further, since the aim is to propose systems of contracts that address most of the uncertainty due to the multi-scale nature of the problem, the method proposed also searches for solutions that minimize the amount of uncertainty not covered by the system of relational contracts (RC). This was articulated by minimizing, on the one hand, the probability of failure (Figure 5.3, Obj. 1; Eq. 26) while maximizing, on the other hand, the conditional probability of failure due to the structure of relational contracts (Figure 5.3, Obj. 2; Eq. 11) so that there was the minimum probability of realizations not covered by RC (Figure 5.3, Unc. F).

$$P(F_{i,j}) = \frac{N(AEI^{F}{}_{i,j})}{N(AEI_{\ i,j})} \tag{5.25}$$

$$P(W_{i,j}) = \frac{N(AEI^{W}{}_{i,j})}{N(AEI_{\ i,j})} \tag{5.26}$$

This resulted in a set of compromise solutions that enabled us to identify not only the relevant and vulnerable/resilient scenarios, but also the trade-offs required for a proper balance of the pros and cons of contracts so as to select the most appropriate policy measures to accompany the chosen infrastructure plan, as described in section 2.3.2, Co-ordination policy options: finding the best model.

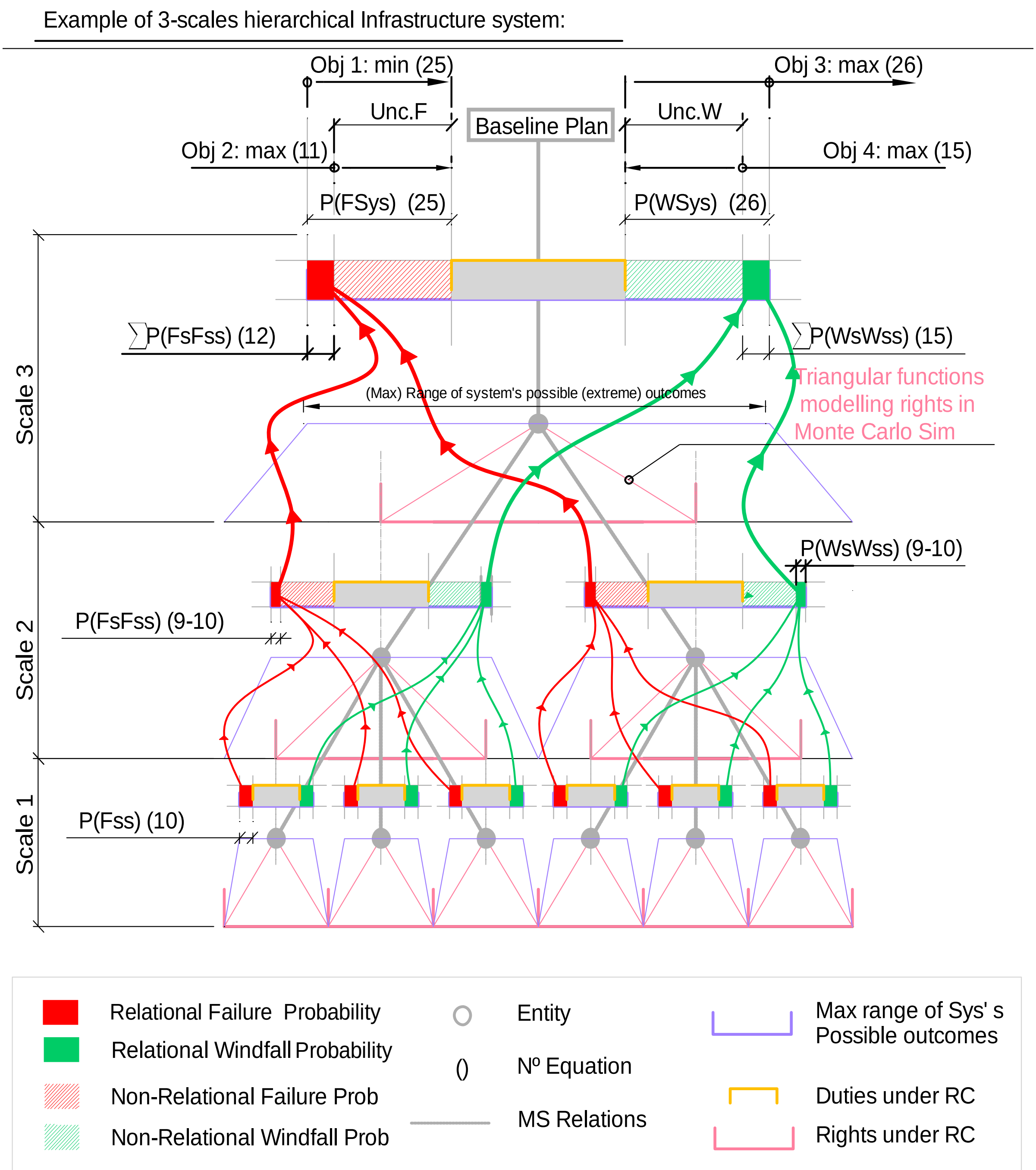


Figure 5.3 Bottom-up propagation through multi-scale hierarchical systems

5.3 Case study

5.3.1. Infrastructure planning to address UV in Spain

In this section, as an exercise to illustrate the usefulness of the framework presented, we considered its application for addressing UV in Spain through infrastructure planning. Following the three-step process mentioned above, the objective is to provide DMs with the guidelines required for the selection of a proper infrastructure plan and its accompanying political measures.

Spain is a country concerned with UV that has given this concept a key role in the development of strategies involving housing, transportation and infrastructure investments (Infrastructure, transportation and housing plan-PITV 2012-2020, Spanish Ministry of Public Works). For the purpose of assessing UV, this country has developed an Observatory of Urban Vulnerability (OUV), offering data over a set of variables regarding UV. As a consequence, UV has been used in this country as a criterion for the selection of eligible projects for receiving funds from the urban I, urban II and IU programs, which in Spain alone assumed a total investment of € 1.037 million between the years 1994 to 2013. However, previous studies reveal resource-allocation problems (Hurtado, 2012) that derive from the lack of capacity of the assessment approaches employed to provide an overall assessment of all the entities being analysed, across the multiple political–administrative scales in Spain (Hurtado, 2017).

Based on the information available in the OVU, Salas and Yepes (2018b) addressed this issue by proposing a methodology, aligned with the latest trends in urban strategic planning, for the evaluation of urban vulnerability in this country. This method provided an assessment of both the state and the risk of vulnerability for cities with a population of more than 10,000, provinces, and regions. Unlike other methods (Table 5.1), the planning system presented in this paper can accept a comprehensive assessment of entities in a territory composed of multiple, inter-related organizational scales, and provide overall plans to be implemented by entities of these scales.

Like other OECD members, Spain is a country which has undergone a strong process of decentralisation, transferring major powers from the central government to the regions, including powers regarding infrastructure investment (OECD, 2007). In order to evaluate the degree of performance achieved in the distribution of resources among the different administrations involved in the process of public infrastructure investment, a survey of urban infrastructure (EIEL) was generated in this country to gather data on a wide range of infrastructures from 2000 onwards (EIEL, 2003). This assessment aims to support the proper assignment of public resources in order to minimize inequities among regions, followed by means of better planning of the public infrastructure investment in municipalities. In other words, the EIEL fosters inter-scale vertical co-ordination as well as horizontal equalization, which are among the challenges for attaining a properly decentralized system (Frank & Martínez-Vázquez, 2015). The data presented in the EIEL comprises a wide range of infrastructures present in municipalities of 50,000 habitants or less in all Spanish regions, with the exception, due to their specific organizational regime, of the Basque Country and Navarra.

Since our method required a comparison between data on urban vulnerability and data on urban infrastructure, first we retrieved from the EIEL the data from the same years and scales in which we had assessed UV, i.e. between the years 2000 and 2010, and structured on the city, province and region (autonomous communities) scales.

5.3.2. Collection of data and set-up of the process

All this information was assembled in an SQL database, which in turn was linked to the

Matlab® code automating the whole process described in the methodology section, including the planning (5.2.2) and the scenarios (5.2.3) modules. Based on the knowledge of the experts involved in this study, a set of 32 variables (Table 5.4) intended to cover relevant aspects of urban planning for dealing with UV was selected. These variables represented the transport, land use, health, educational, green and recycling infrastructures. Taylor et al. (2006) included attributes concerning the pavement condition and a roads administrative scale for characterizing the vulnerability of strategic road networks, which might have important consequences for socio-economic activities in cities and regions of Australia. Land-use planning and the location of health and educational centres have also been identified as important parameters for strategic decisions regarding regional and urban vulnerability (Menoni and Pergalani, 1994). Voskamp and Van de Ven (2014) pointed to parks and other green infrastructures as suitable means of reducing urban vulnerability to extreme weather events, while Ma and Hipel (2016) related effective and efficient municipal solid waste management with the social dimension of urban vulnerability.

On the other hand, a UVA model was chosen (Figure 5.2, I-0) by following the discursive approach described in a previous work (Salas & Yepes, 2018b), which allowed the process to be initiated. As a subsequent step, the data collected on urban infrastructure were considered as explanatory variables, while those of the UV assessment were taken as the response variable in the regression model. Following the process described in section 5.2.2., a predictive model was then fitted for each governmental scale, comparing the evolution of infrastructure equipment along the period considered with that of urban vulnerability, which enabled an appraisal to be made of the consequences, in terms of the impact on urban vulnerability, of the evolution of the urban infrastructures contained in each entity. In this way, the objective of the UV impact became operative, while for the economic impact, costs were assigned to the infrastructure alternatives (Table 5.4).

Regarding the robustness objective, we followed the process described in the methodology section, producing 100 random outcomes for each candidate via the Monte Carlo simulation method. The program was coded in Matlab® with an INTEL® CoreTM i7-4712 CPU processor at 2.3 GHz. Starting from an initial random population of 500 individuals, 500 iterations were set as the maximum number of generations to be obtained. Crossover and mutation probabilities were set to 0.6 and 0.5, respectively.

5.3.3. Running the process

From the planning module, we obtained a set of Pareto-optimal urban infrastructure plans satisfying the abovementioned objectives, which we analysed in order to obtain the guidelines required for informed decision-making. As expected, these solutions showed the trade-offs between the criteria used for the assessment, enabling DMs to select a set of relevant planning alternatives for further assessment (**I-1**). In a subsequent step, this set of solutions was used to generate, through the scenarios evaluation method described in section 5.2.3.3, the space of plausible scenarios attached to the decision space (Figure 5.2, **SM-I**). This method allowed us to quantify, based on the failure and windfall thresholds (section 5.2.3.3, Figure 2, Sc-1), both scenarios' vulnerability and resilience, and determine, according to the vulnerability and resilience thresholds (section 5.2.3.3 Figure 5.2, Sc-2), a set of relevant SOWs. This enabled the analyst to check the behaviour of solutions across the set of relevant SOWs in terms of their performance under such assumptions, and to select a desired investment planning according to the knowledge derived from scenario analysis (**I-2**).

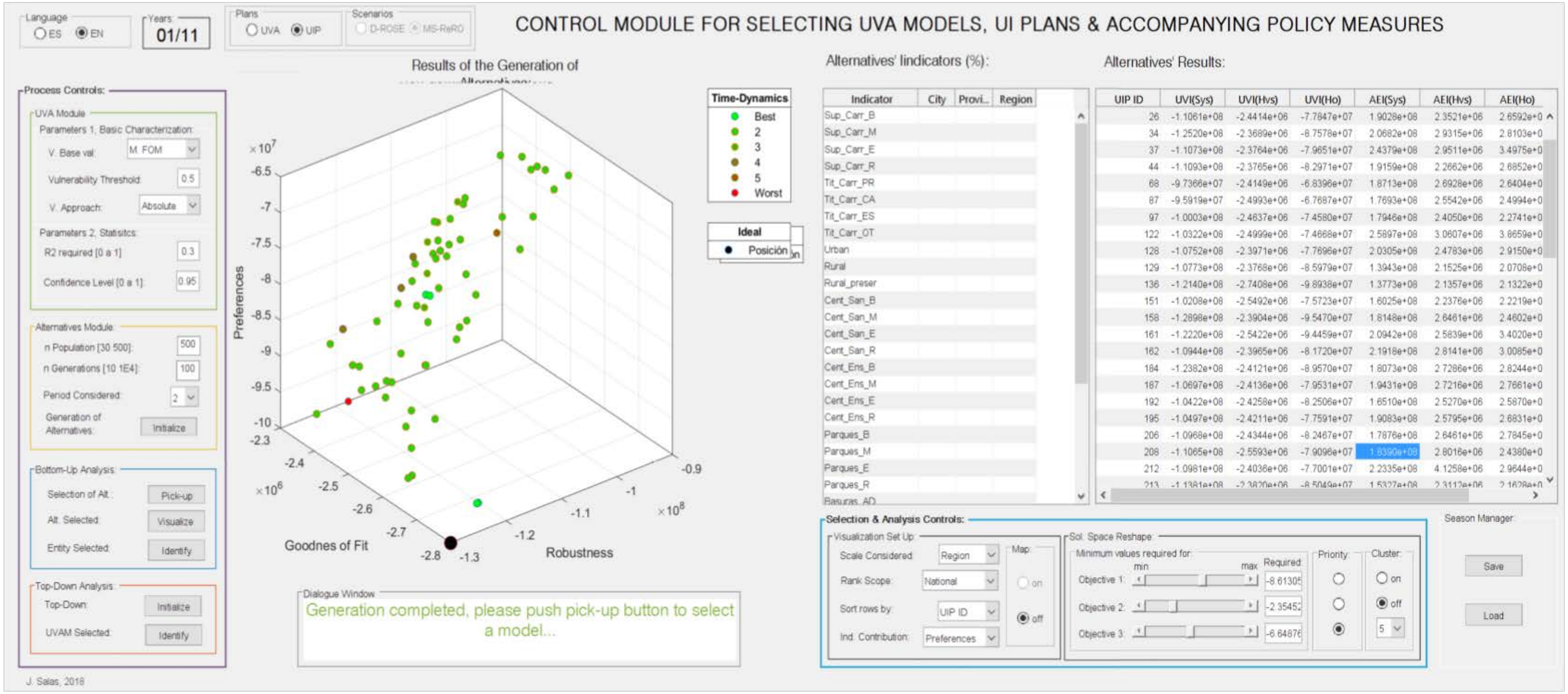
With this knowledge, an infrastructure model was selected (**I-2**) for further analysis through the MS-ReRO module (Figure 5.2, **SM-II**). This resulted in a set of compromise solutions, each of them corresponding to a given set of rights and duties embodied by the inter-scales relational contracts, i.e., with each of the political-administrative scenarios considered in our problem (section 5.2.3.4). In a subsequent step, a desired system of accompanying policy measures was selected (**I-3**), enabling the improvement of UV in the cities, provinces and regions analysed through a proper realization of infrastructure planning.

5.4 Results

5.4.1. Step 1, Guidelines from Planning alternatives (I-1)

The abovementioned process was used to yield the results needed for the interactions required by the method. In the first stage, i.e. the generation of planning alternatives, a set of Pareto-optimal solutions was obtained. The interpretation of these results provided guidelines regarding the trade-offs between the different objectives considered. This enabled us to draw conclusions on the behaviour of the models in terms of their economic and vulnerability impacts on the different interest groups selected, as well as on their robustness to uncertainties regarding economic costs (Table 5.6). With the knowledge thus acquired, DMs were in a better position to set bounds and to reshape, according to their requirements, the set of initial solutions to obtain a set of relevant UIPs (Figure 5.2) for further analysis in the Scenarios module.

Video 1 portrays the trade-off between the UVI(Sys), UVI(Hvs), UVI(Ho) and AEI(Sys) objectives.



Video 5.1 Selection of relevant UIP

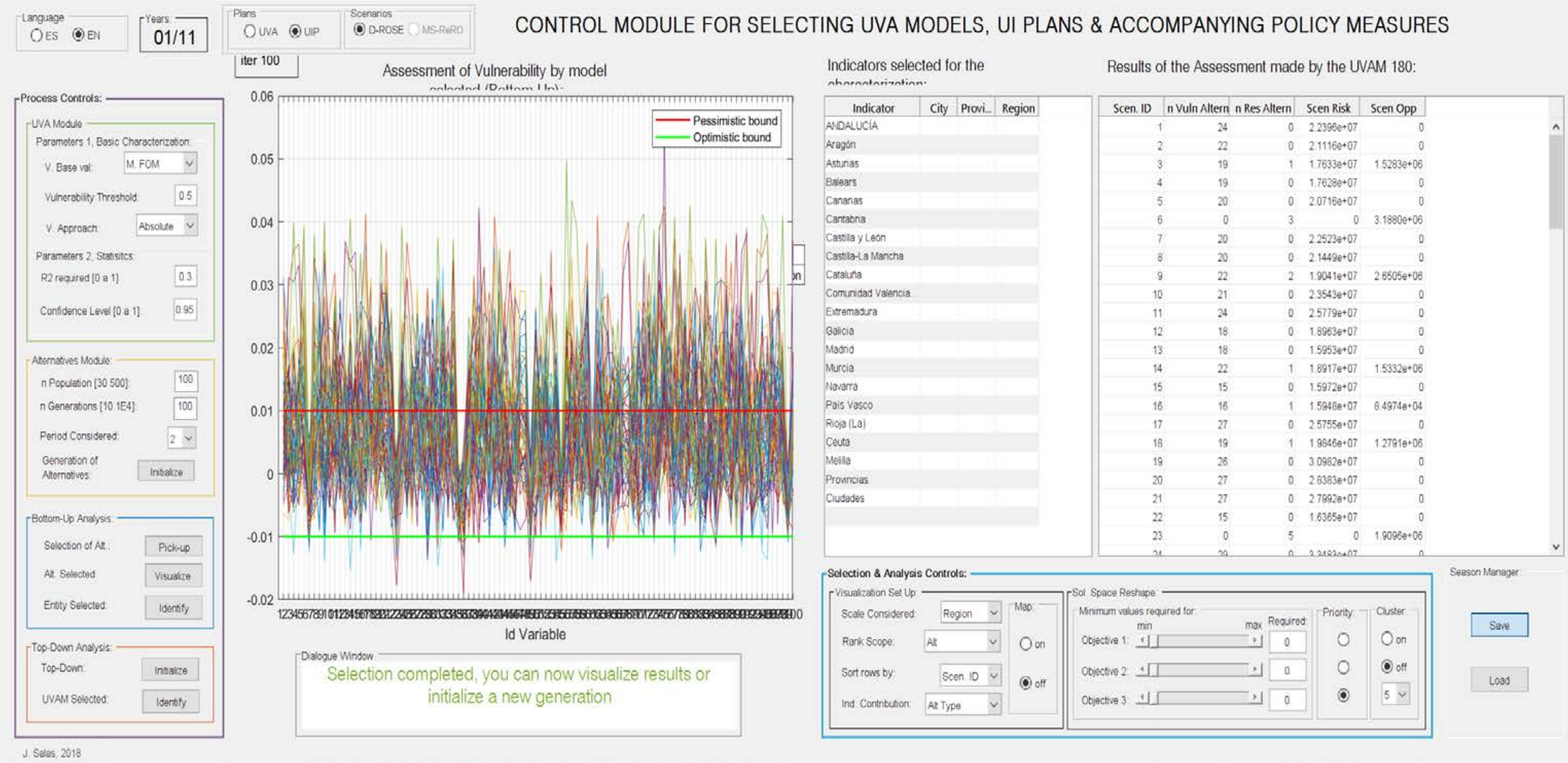
In addition, we implemented a semi-automated alternative to enhance the extraction of guidelines. The solutions gathered were clustered according to their performance and the AEI(Sys) objective. As a result, the following guidelines were elicited after step 1 (Figure 5.2, I-1):

- Most of the solutions that perform well in terms of (lower) overall vulnerability impact are also good in terms of their impact on the opportunity group, suggesting that these two aspects are directly linked.
- Solutions with low (best) economic costs, marked in red, are prone to have higher impacts on the most vulnerable group of entities and vice versa: expensive solutions are worst for this group. On the other hand, it is possible to identify planning alternatives that are good for the overall and high vulnerability impacts in areas with relatively lower costs.
- The impact on entities of the most vulnerable group UVI(Hvs), on the other hand, does not follow UVI(Sys) or UVI(Ho). However, it appears to also have a direct relation with economic costs (green alternatives close to, and red far from, the best UVI(Hvs)), showing that these two objectives are aligned.

5.4.2. Step 2, Guidelines for risk and opportunity balance from D-ROSE (I-2)

After defining the relevant set of UIPs, and prior to running the Scenarios Module, we selected the optimistic and pessimistic thresholds needed to consider whether alternatives had rendered windfalls or failed under each of the scenarios formulated (Figure 5.2, Sc-1). On this basis, the different SWO realizations generated by the D-ROSE module were classified as failure, normal or windfall outcomes of the planning being analysed, allowing us to determine the number of vulnerable and resilient scenarios and alternatives, as well as the risks and opportunities associated with them.

The analysis of the results for the second step (Video 2) allows us, as in the previous case, to extract the guidelines for identifying a set of relevant scenarios. In this case, we selected scenarios presenting high levels of vulnerability (Table 5.6, TVul= 5.2), which we used, in turn, to determine which alternatives behave better under the set of relevant scenarios. For the selection of the set of relevant scenarios, the DMs dynamically set up the resilience and vulnerability thresholds (Figure 5.2, Sc-2).



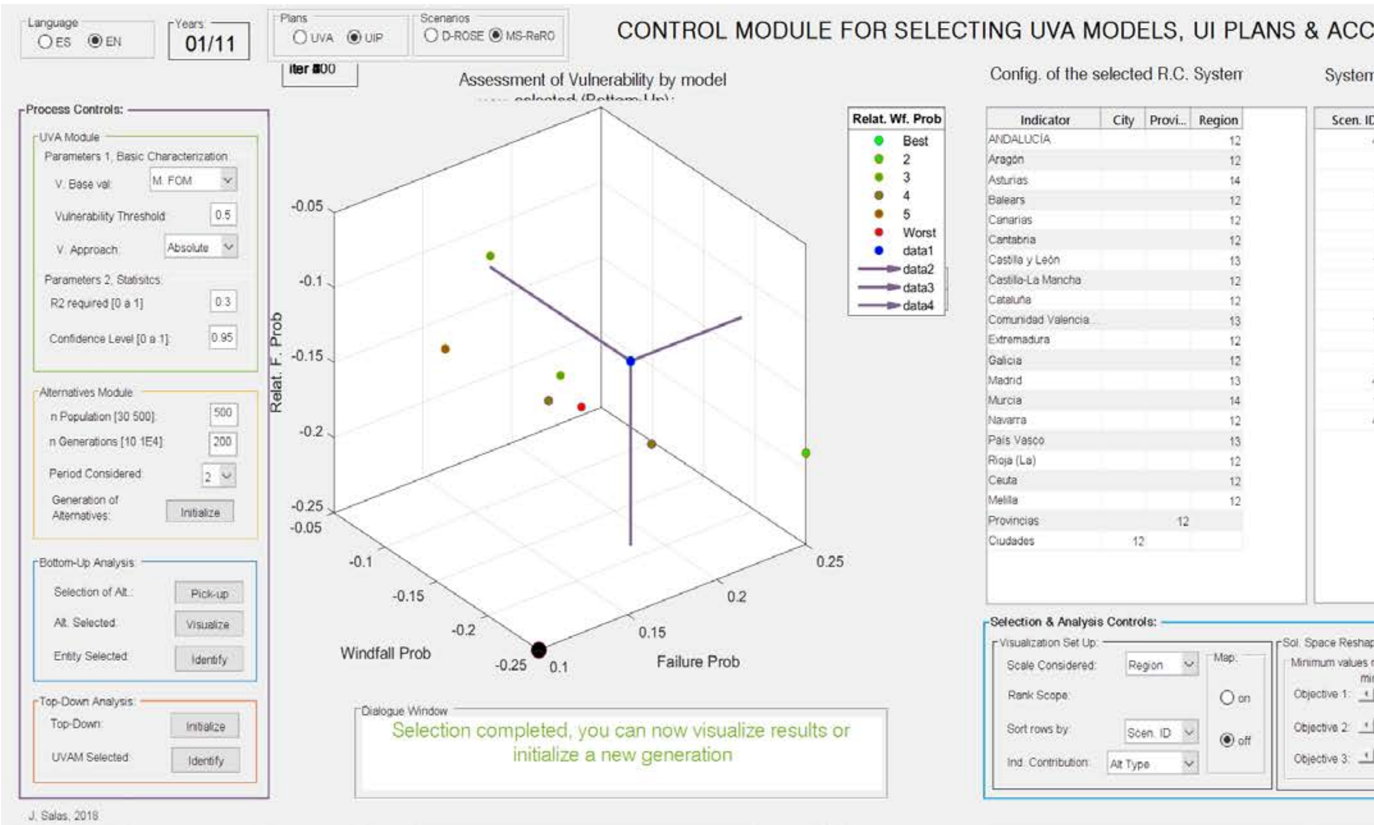
Video 5.2 Selection of relevant scenarios and planning alternatives via D-ROSE

On this basis, the following guidelines can be drawn up for the set of relevant scenarios and the selection of a desired planning alternative (Figure 5.2, I-2):

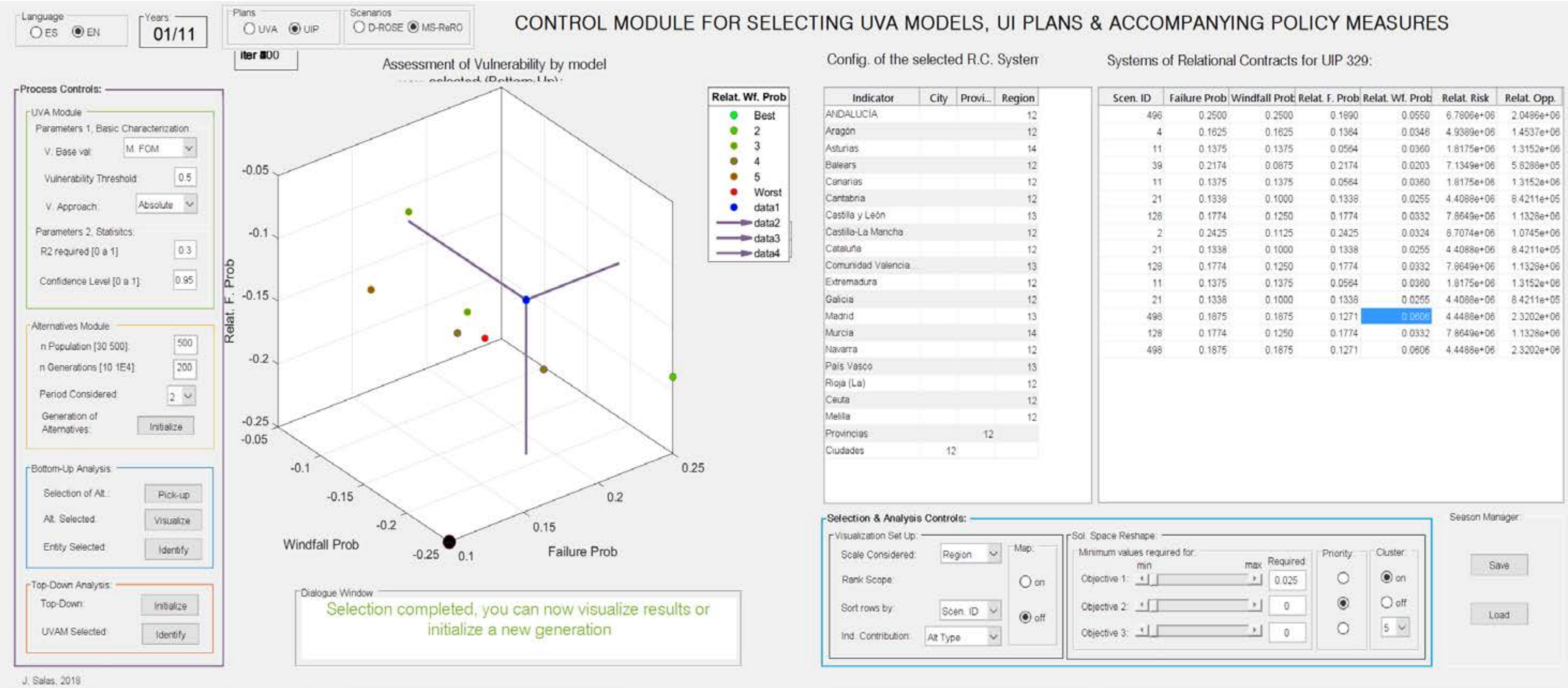
- D-ROSE identified 7 relevant alternatives that are resilient in at least 2 scenarios. Of these alternatives, ID 56 is the best (cheapest) solution for the overall cost objective, but had a poor balance of risks and opportunities and a high number (11) of relevant scenarios beyond the pessimistic bound. ID 56, as well, presented the best balance between risks and opportunities, while at the same time performing worst in the overall cost objective (is the most expensive alternative).
- Along with Alt ID 56, Alt 40 had the least number (7) of relevant scenarios beyond the pessimistic bound. In addition to this, Alt 40 had 3 relevant and total scenarios beyond the optimistic bound, while ID 56 had just one, and maintained an acceptable medium-to-good performance in the overall cost objective, leading us to select this as the desired planning alternative.

5.4.3. Step 3, Guidelines for risk and opportunity balance from the MS ReRO (I-3)

The abovementioned guidelines motivated the selection of Alt-ID 40 for subsequent analysis in the MS-ReRO module, which offered policy measures in the form of relational contracts between inter-governmental scales, and evaluated them in terms of the risks and opportunities (Table 5.6) associated with each of these policy scenarios.



Video 5.3



Video 5.3 Selection of accompanying policy alternatives from clustered group

As in the case of the planning module, the results were filtered following the DM preferences from the MS-ReRO Scenario module, and then clustered into 9 partitions, according to the opportunity objective. The following guidelines were inferred from this step:

- The optimization process yielded several solutions in which the total failure probability was covered by the relational failure probability risk.
- The relationship between failures and windfalls presents high nonlinearities. Indeed, the best solution from the relational windfalls point of view (video 3, green legend) shows a relational failure probability close to that of the alternatives with the least relational windfall probability (video 3, red legend). However, a faint inverse relationship can be observed.
- There are compromise solutions yielding results close to the best regarding both opportunities and risks.

The insights above enabled us to identify alternatives that present a good balance between risks and opportunities. Although Scen-ID 11 presented the best combination of high opportunity and low risk (ReOpp/ReRisk=0.724), we dismissed this alternative because it had a high proportion of failure risk not covered by the relational risk (TotFail-ReFail=8.11%), which can lead to failures out of the scope of the relational system. We therefore chose the Scen-ID 498 (ReOpp/ReRisk=0.522; TotFail-ReFail=6.04%) as the most appropriate set of policy measures to accompany the urban infrastructure plan previously selected. This alternative embodied the rights to be transferred, through relational contracts, from the central government to each of the 17 regions and 2 autonomous cities of Spain, as well as those from regions to provinces and from provinces to cities in general (Table 5.6).

5.5 Discussion

Bottom-up can be generalized into four steps: generating decision alternatives, sampling SOWs, specifying scenarios criteria and evaluating the alternatives in terms of their relations with the scenarios that meet these requirements (Table 5.4). Info-Gap identifies alternatives that perform well, i.e. satisfying the scenarios criteria, among all the plausible scenarios, from which the alternatives' robustness and opportunities are derived, enabling the DM to balance potential windfall against consistent robustness. Robust Decision Making (RDM) (Lempert et al., 2006), on the contrary, is a PSS focused on vulnerabilities (scenarios where more alternatives perform worst), in which solutions are deemed to be robust when they do not perform worst and minimize the deviation between their performance in the worst-case and base-line scenarios. Through the analysis of the trade-offs between scenarios' characteristics and vulnerabilities, RDM also provides valuable insights to inform the adaptive management of complex environmental systems undergoing change (Kasprzyk et al., 2013).

Like RDM, the Dynamic Adaptive Policy Pathways (DAPP) approach (Haasnoot et al., 2013) is based on worst-case study, and identifies the sequence of policy actions that enables the preferred alternative to go on being valid over time. In other words, DAPP addresses time-dependent uncertainties arising from the dynamic nature of the planning problem being analysed, by evaluating alternative paths for when the current route, at a given moment, will cease to be adequate. This means that DAPP is intended to provide sets of policy actions for a discrete and relatively small set of alternatives, instead of providing robustness assessment for a large set of alternatives across a wide range of scenarios, as in RDM or Info-Gap (Ray & Brown, 2015).

Like DAPP, Decision Scaling provides a discrete choice framework to assess pre-specified design alternatives or to perform vulnerability analysis of existing systems (Ray & Brown, 2015). As in the case of RDM, Decision Scaling focuses on vulnerabilities, i.e., it identifies scenarios leading to a system's failure, and identifies thresholds that are likely to trigger those vulnerabilities. In contrast with other bottom-up methods, Decision Scaling relies on a subjective estimation of the SOW probabilities obtained through expert evaluation (Hadka et al., 2015).

By identifying failure or windfall events, the abovementioned methods provide risk or opportunity assessment, enabling DMs to learn from the trade-offs between each of them and the general results (Table 5.5). However, none of the planning systems revised provides planners with an actual risk or opportunity assessment of the planning alternatives. IPSS evaluates alternatives for a set of climate change scenarios, but do not determine risks, nor compares the behaviour of planning alternatives between them to find out which of them offers better prospects given a range of possible future states of the world. The proposed method, in contrast, provides planners with both a risk and opportunity assessment, enabling them to identify solutions that remain valid for a larger portion of uncertainty.

This enriches the elicitation of knowledge from trade-offs which, in the case of D-ROSE, is improved by the ex post, dynamic selection of criteria for the delimitation of relevant scenarios. In contrast, both RDM and Info-Gap employ an ex-ante definition of thresholds for delineating sets of relevant scenarios, which does not contribute to a better understanding of the relations between thresholds and scenarios. D-ROSE, in addition, allows this trade-off to be extended to the case of alternatives, allowing us to determine trade-offs among thresholds and vulnerable/resilient alternatives. All this together allows a minute examination and balance of the pros (opportunities) and cons (risks) of the alternatives for a very specific set of scenarios, while keeping in mind a general overview.

The presented method, however, does not claim to automatically provide guidelines for the selection of alternatives, which depends on the specific wishes and ambitions of the decision-makers. Instead, it offers guidance to decision-makers for the essential task of analysing the behaviour of the alternatives with regard to the modelled uncertainties, to enable them to draw their own conclusions and decide accordingly.

Table 5.7 illustrates the efficacy of the method proposed by comparing the closeness between the selected planning alternative and the ideal alternative, with that of the other optimal alternatives generated to the ideal. We can see how this ideal, defined as the best value of each objective, changes when considering all or only the relevant alternatives, indicating the effect of the decision-makers' preferences on the balance of objectives and therefore on the outcome of the selection process. As a consequence, the distance of the selected alternative from the ideal varies from one set to another, as does the ratio between alternatives farther from the one selected, and alternatives closer to the ideal. The reason why this ratio decreases when moving from considering all to only considering relevant alternatives, is because in the second group we have eliminated non-attractive solutions, thus reducing the number of farther solutions.

Objectives			Distance to Ideal of the Selected alternative	
Item (Table 5.6)	Ideal values			
	All	Relevant	All	Relevant
Planning Module:				
UVI(Sys)	-1.47E+08	1.29E+08	24%	20%
UVI(Hvs)	-2.81E+06	2.74E+06	14%	47%
UVI(Ho)	-1.02E+08	9.89E+07	13%	22%
AEI(Sys)	1.25E+08	1.38E+08	42%	38%
AEI(Hvs)	2.11E+06	2.14E+06	22%	21%
AEI(Ho)	1.92E+07	2.07E+07	44%	41%
Rob(Sys)	22.55	22.52	76%	76%
Aggregation of distances			235%	265%
Number of alternatives farther to Ideal			340	42
Number of alternatives closer to Ideal			159	23
Ratio farther/closer			2.14	1.83
Scenarios Module, D-ROSE:				
N(Scen_Vul)	5	7	4%	0%
N(Scen_Res)	16	16	87%	93%
AltR	7.59E+04	7.12E+05	7%	5%
AltO	1.99E+07	1.99E+07	97%	97%
Aggregation of distances			194%	195%
Number of alternatives farther to Ideal			64	8
Number of alternatives closer to Ideal			1	1
Ratio farther/closer			64	8

(*) Planning module's "relevant" alternatives in the are the Scenarios module's "All" alternatives

Table 5.7 Comparison of the selected alternative with the sets of all and relevant alternatives

Table 5.7 also shows how the suitability of the selected alternative changes depending on whether it is evaluated in terms of planning or scenarios objectives. While the ratio of farther/closer alternatives in the first case was 1.83, in the case of scenario analysis this value, for the same set of alternatives, rose to 64. This means that, although the selected alternative performance was only good in terms of the planning impact (23 closer alternatives), it performed much better in terms of risks and opportunities (1 closer alternative). The reason for choosing alternative 40 instead of alternative 56 (the closest to the ideal) is explained in section 5.4.3. Both of these, however, were suitable candidates, and illustrated the capabilities of this method, demonstrating its efficacy for identifying planning alternatives that are robust to risks, sensitive to windfalls and efficient in attaining the planning objectives.

As to the dynamic nature of many problems, in those regarding USP and UV this is present in both their temporal and socio-political dimensions (Salas & Yepes, 2018a), which are sources of uncertainty that must be addressed. Regarding the time dynamics, on the one hand, the DAPP provides policy alternatives for overcoming contextual problems that may arise, at different moments (tipping points), along the development of an alternative/project. MS-ReRO, on the other hand, deals with the uncertainty attached to coordination problems when implementing alternatives through the multiple political–administrative scales of a system. Regarding trade-offs among short- and long-term temporal scales, MS-ReRO can be used in combination with methods already developed (Sierra et al., 2018b) for addressing this issue.

5.6 Conclusions

In pursuit of sustainable urban development, the improvement of UV is a key issue that is essential for urban management. This paper presented a comprehensive DSS for urban infrastructure planning that aims to cope with UV, integrating methods for the generation of both optimal plans and scenarios and their analysis, and proposing accompanying policy measures in a 3-step process following a discursive approach. The framework presented makes extensive use of visual analytics to conduct the discursive approach in a cognitive way, and implements two novel methods, the D-ROSE and the MS-ReRO, for scenario design and analysis, as presented in sections 5.2.3.3 and 5.2.3.2, and discussed in section 5.5.

Like methods based on scenario discovery (Bryant & Lempert, 2010), the D-ROSE generates scenarios and identifies vulnerabilities as a function of SOWs that drive alternatives (plans) to extreme undesired values. The D-ROSE, however, also identifies windfall outcomes, enabling us to assess both the vulnerability and resilience of scenarios, from where risk and opportunity are derived. Another unique feature of the method presented lies in how the vulnerability and resilience criteria are applied. While in other methods the vulnerability (or resilience) criterion is set up ex ante, without deriving previous knowledge from the full set of scenarios, D-ROSE provides DMs with this knowledge by enabling them to dynamically set up the vulnerability and resilience criteria after extracting guidelines from previous sets of scenarios. From the set of relevant scenarios, D-ROSE derives, for each alternative, the associated risks and opportunities, improving the background available for an informed selection of planning alternatives. In this way, the DMs can choose planning alternatives that are robust to vulnerable scenarios and sensitive to resilient ones.

While D-ROSE takes into account the overall uncertainty borne by the system, MS-ReRO specifically focuses on the relational uncertainty arising from the system's multi-scale nature, and assesses the risks and opportunities attached to it. This enables us to propose optimal, ad hoc relational contracts as policy measures to accompany the investment plan selected (Frank & Martínez-Vázquez, 2015).

As to the urban infrastructure planning module (section 5.2.2), the framework provides planners with a set of compromise solutions in which the impacts on both UV and economic costs are evaluated across the multiple scales of a territory (section 5.2.2.1), as well as the robustness against uncertainties attached to the costs of actions (section 5.2.2.3). Besides, stakeholders are represented as overall, high vulnerability and high opportunity interest groups (section 5.2.2.2). In this way, the method overcomes (Figure 5.1) the limitations shown by other urban , such as AST, APST and IPSS, in the attainment of the characteristics demanded by USP (Table 5.1).

Then, the whole process was tested via a case study. For this purpose, Spain has been used as an example, and quantitative data on the city, province, region and country political–administrative scales were gathered. With this information, the process was performed, and the results showed that the method supports informed decision-making on UIPs evaluated under a set of relevant scenarios. In addition, the framework proposes policy actions, according to a desired trade-off between inter-scale relational risks and opportunities, to accompany the UIP selected in its implementation across political–administrative scales.

Despite the remarkable outcomes, there are still limitations to this study. While dealing with multi-scale dynamics, the framework revealed the shortcomings of a method such as DAPP when dealing with time-dependent planning dynamics. In addition to this, the scenarios module does not yet have a multi-objective capacity, though this should be attained in future research. Moreover, D-ROSE does not analyse the relations between the uncertainty variables that configure the scenarios and the vulnerable or resilient outcomes, which should again be the subject of future work. Finally, more research is needed for providing objective criteria on how to balance risks and opportunities, for example by examining the applicability of the anti-fragility concept (Taleb, 2018) in the selection of planning alternatives.

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Capítulo 6
Discusión

Discusión

En este capítulo se evalúa el grado de respuesta que esta investigación ofrece a las cuestiones que la motivaron.

6.1 Primera pregunta

Respecto a la primera pregunta formulada: ¿*Qué condiciones debe cumplir todo modelo de evaluación de vulnerabilidad urbana para que pueda integrarse con el resto de procesos de planificación estratégica urbana*?, debe indicarse que se han identificado seis atributos característicos de los procesos actuales en el campo de la planificación estratégica urbana, y que por lo tanto deben estar presentes en los métodos de evaluación de vulnerabilidad urbana. Así, estos modelos deben ser robustos frente a la incertidumbre; ser participativos y capaces de incorporar subjetividades procedentes de los diferentes interesados, tener en cuenta la naturaleza dinámica de la vulnerabilidad urbana en sus dimensiones tanto temporal como a través de las múltiples escalas político-administrativas en las que se desarrolla, estar dotadas de capacidad estratégica y multiobjetivo, y emplear un enfoque cognitivo.

Sin embargo, la presencia de estos atributos en el ámbito de la evaluación de vulnerabilidad urbana es muy desigual. Mientras que algunas características, como las de ser robusto o participativo, pueden encontrarse con frecuencia incorporados en métodos de evaluación urbana, otras apenas han sido exploradas. También desde un punto de vista cualitativo, se puede apreciar una gran heterogeneidad en los grados de cercanía de las técnicas empleadas, con aquellas ya presentes en el ámbito de la planificación estratégica urbana. Así, mientras que técnicas como las utilizadas para evaluar la robustez están próximas, aquellas destinadas a dar cuenta de la naturaleza multi-escala se encuentran muy alejadas.

Por otro lado, se ha identificado una correlación entre el número de estos atributos que se encuentran presentes en un mismo método, y el nivel que este ocupa en la escala evolutiva de métodos de evaluación de vulnerabilidad urbana: aquellos procesos que integran un mayor número de estos atributos, se encuentran más próximos a la etapa discursiva, actualmente a la vanguardia de la planificación estratégica. Este grado de integración, sin embargo, resulta bastante reducido, siendo pocos los métodos que integran más de dos atributos.

Esta relación entre atributos y etapa evolutiva no es la única que se ha observado. Se ha apreciado también una fuerte presencia de los atributos de robustez y, en menor medida, de capacidad estratégica, en métodos con enfoque biofísico, que son los que actualmente presentan una tendencia ascendente, en contraste con los métodos de enfoque socio-económico.

Cabe esperar, por tanto, que las técnicas de evaluación de robustez y optimización multi-objetivo continúen desarrollándose mientras que otros claramente infra-investigados, como los relativos a la naturaleza multi-escala, o el nivel de integración de diferentes atributos en un mismo método, siga sin acercarse a los niveles marcados en el campo de la planificación estratégica. Por ello se sugiere el desarrollo de metodologías de evaluación de vulnerabilidad urbana que integren el mayor número posible de los atributos anteriormente identificando, pero poniendo un mayor énfasis en el uso de enfoques cognitivos, multi-objetivo, y que incorporen las dinámicas temporales y multi-escala.

6.2 Segunda pregunta

Respecto a la segunda pregunta formulada: ¿ *Qué modelo de evaluación cumpliría con las condiciones exigibles a todo MEVU*?, dichos atributos toman cuerpo en el método de evaluación de vulnerabilidad urbana planteado en el capítulo 3, que emplea un enfoque discursivo para ofrecer modelos de evaluación tanto de los niveles actuales de vulnerabilidad urbana, como del riesgo de incrementarla en un período futuro, de las entidades que conforman un territorio a lo largo de las diferentes escalas político-administrativas que lo componen (Figura 6.1).

	Marco EVU:	VisualUVAM:
Robustez	-	Obj. Robustez
Participativo	Id. Preferencias	Obj. Preferencias
Multi-Escala	E. Multi-Escala y Relativa	Objetivos bondad x escala. Objetivo similitud
Temporal	Riesgo	Obj. Conexión Temporal
Multi-Obj	-	Algoritmo Búsqueda
Cognitivo	-	Interacciones, A. Visual

Figura 6.1 Cumplimiento requisitos por el método propuesto

El capítulo 4, por su parte, compara el método de evaluación de vulnerabilidad urbana utilizado en el Observatorio de Vulnerabilidad Urbana con el presentado en el capítulo 3, y señala las aportaciones de este último con respecto al primero (Figura 6.2). A grandes rasgos, estas aportaciones son el resultado de incorporar los atributos detectados al proceso de evaluación, y entre ellas destacan que el proceso presentado encuentra alternativas relevantes que satisfacen múltiples criterios de forma simultánea, aprovecha las ventajas de integrar información cuantitativa y cualitativa, hace partícipes al conjunto de expertos en la generación de alternativas, explora un universo amplio de alternativas y los sintetiza en un número manejable de opciones entre las que elegir. Así mismo, la formulación que se propone del fenómeno de Vulnerabilidad Urbana considera los aspectos dinámicos del mismo tanto a lo largo del tiempo como de las estructuras administrativas en las que se desarrolla, ofrece una evaluación consistente e integral a lo largo de las escalas barrio, municipio, provincia y región, y permite contextualizar las entidades evaluadas en diferentes ámbitos.

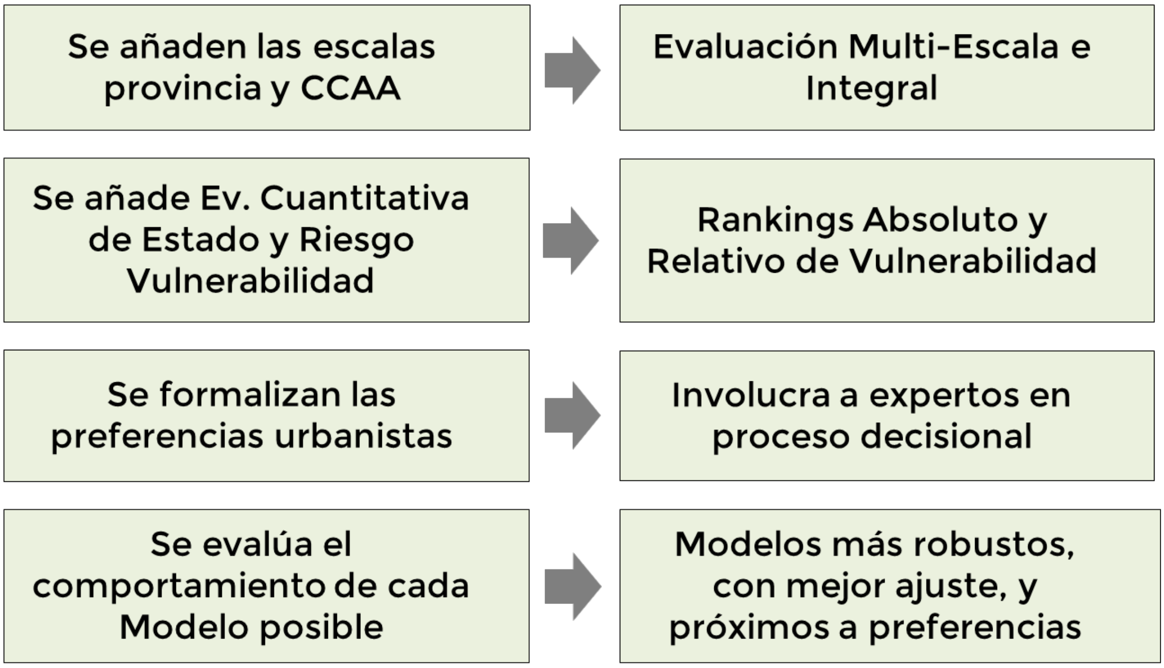

Figura 6.2 Avances con respecto a OVU

El sistema decisional presentado en el capítulo 5, a su vez, incorpora el modelo de evaluación de vulnerabilidad urbana seleccionado en el ejercicio práctico anterior con otro en un proceso de planificación estratégica urbana que propone alternativas de planificación, y las evalúa conforme a una serie de objetivos y escenarios posibles. De esta manera, se verifica la integración del modelo de caracterización desarrollado con otras herramientas propias del campo de la planificación estratégica.

6.3 Tercera pregunta

Respecto a la tercera pregunta formulada: ¿*Cómo determinar el conjunto de escenarios deben considerarse, y que estrategias hay que resulten robustas frente a los riesgos y a la vez sensibles ante eventuales oportunidades*?, el sistema decisional presentado en el capítulo 5 permite acotar un conjunto relevante de escenarios desde el punto de vista de los riesgos y oportunidades que representan para un conjunto de alternativas de planificación previamente definido. Sobre esta base, el sistema decisional identifica alternativas robustas y sensibles frente a escenarios especialmente neativos y positivos respectivamente.

A diferencia de otros métodos de evaluación de incertidumbres con enfoque bottom-up como RMD, Info-Gap, Decision Scaling o DAPP, que basan su análisis en el comportamiento de las alternativas dado un conjunto de escenarios extremos óptimos o pésimos, el método D-ROSE realiza su análisis a partir de un conjunto que incluye tanto escenarios óptimos como pésimos, y que conforma el contexto en el que las alternativas van a ser evaluadas. Además, incorpora como novedad una selección ex post de este contexto, o conjunto de escenarios. Esto es, mientras en otros métodos el criterio de selección de escenarios relevantes se produce antes de conocer el resultado de la generación de escenarios, en el caso de D-ROSE el criterio se selecciona de forma dinámica una vez generado el escenario. Esto supone una generalización con respecto al resto de métodos de análisis de incertidumbre, permitiendo analizar el efecto de un contexto determinado sobre el conjunto de alternativas (Figura 6.3).

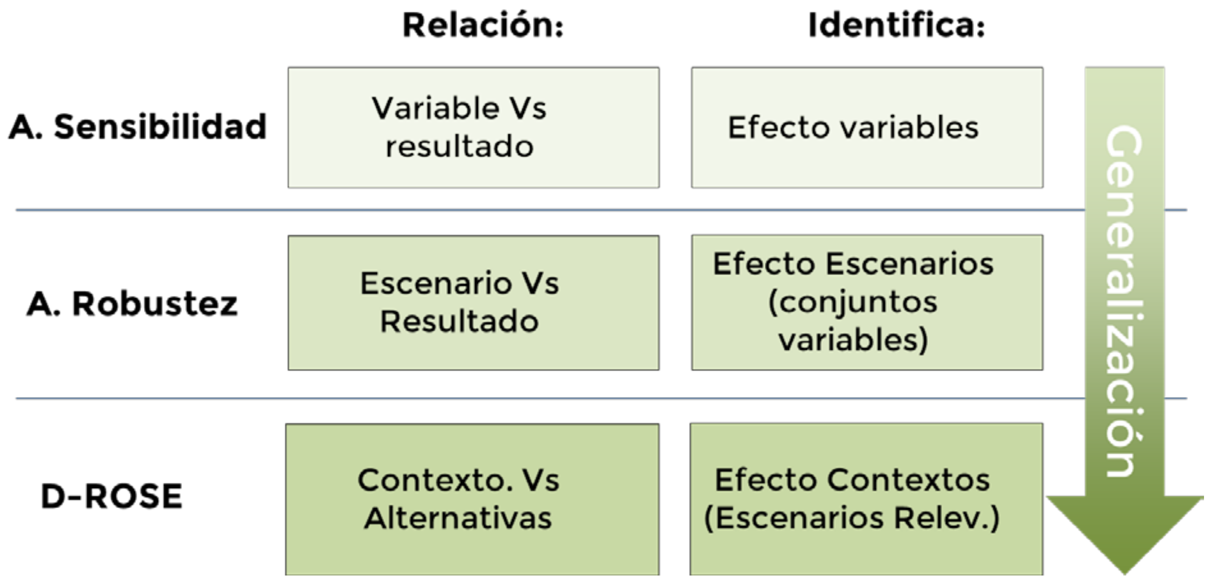

Figura 6.3 Generalización análisis incertidumbre

D-ROSE evalúa los riesgos y oportunidades soportados por cada alternativa en relación al conjunto de escenarios, permitiendo identificar qué alternativas presentan un balance adecuado de robustez frente a escenarios indeseados (menor número de escenarios relevantes en los que la alternativa es vulnerable), y sensibilidad hacia a escenarios mejores de lo previsto (mayor número de escenarios relevantes en los que la alternativa es resiliente).

Por otro lado, el uso de técnicas de visualización interactivas en el modelo decisional del capítulo 5, junto con la posibilidad de identificación directa de los escenarios que ofrece D-ROSE, facilitan realizar un análisis particularizado de aquellas alternativas o escenarios que resulten de especial interés. Para ello, es posible identificar qué alternativas resultarían ser vulnerables o resilientes en un escenario determinado (enfoque bottom-up) o viceversa, en qué escenarios una alternativa determinada resultaría ser vulnerable o resiliente (enfoque top-down). De este modo, se pueden evaluar las alternativas tanto de forma cuantitativa, es decir, en función del resultado de la evaluación de riesgos y oportunidades, como emprender un análisis cualitativo en función de la valoración que realice el decisor de la casuística particular de cada uno de los escenarios que afectan a una alternativa.

6.4 Cuarta pregunta

Respecto a la cuarta pregunta formulada: ¿*Qué sistema de medidas político-administrativas resulta adecuado como acompañamiento de una determinada estrategia en su implementación a través de las diferentes escalas del sistema*?, el método MS-ReRO, presentado el el caítulo 5, realiza una evaluación de la incertidumbre relacional asociada a la configuración multi-escala de un sistema, a partir de la cual pueden identificarse medidas de acompañamiento.

El caso de España, como el del resto de miembros de la OCDE, es el de un país que ha alcanzado un alto nivel de descentralización, con la consiguiente carga de incertidumbre relacional sobre una eventual propuesta de planificación integral de infraestructuas. En este sentido, los contratos relacionales entre entes gubernamentales de diferentes escalas son el mecanismo más adecuado como marco de coordinación. MS-ReRO modeliza el contexto político-administrativo en el que debe implementarse una alternativa de planificación en forma de sistema jerárquico multi-escala, en el que las entidades transfieren sucesivamente parte de su capacidad de decisión a aquellas que tienen por debajo, comenzando desde la escala superior (país). Los resultados de las decisiones, por el contrario, se propagan de abajo a arriba, de tal modo que las decisiones tomadas por las entidades inferiores, dentro de las atribuciones conferidas en el contrato relacional, afectan a las superiores, pudiendo comprometer o mejorar la consecución de los objetivos globales esperados. MS-ReRO evalúa hasta qué punto una determinada configuración de las atribuciones que van a ser transferidas entre escalas puede afectar la consecución de un objetivo global, y permite por tanto buscar aquellas configuraciones que presenten un mejor balance entre los riesgos y las oportunidades asociados a ellas. Estas configuraciones serían, en definitiva, los parámetros que definen los contratos relacionales a través de los cuales se implementaría una determinada alternativa de planificación urbana, es decir, el conjunto de medidas político-administrativas de acompañamiento requeridas en la pregunta de investigación.

Capítulo 7
Conclusiones

Conclusiones

7.1 Conclusiones

Esta investigación explora la posibilidad de plantear tanto modelos de evaluación de vulnerabilidad urbana (MEVU), como planes de actuación con los que hacerla frente, alineados con las últimas tendencias en el campo de la planificación estratégica urbana. A lo largo de esta tesis, se han identificado los criterios clave que definen la vanguardia actual en planificación estratégica como paso previo al diseño de una herramienta decisional que los integre. En esta, el decisor puede evaluar un conjunto de posibles MEVU construídos a partir de información tanto cuantitativa como cuantitativa, y seleccionar aquel que ofrezca el balance más adecuado entre los objetivos de ajuste estadístico, alineación con las preferencias de los involucrados y robustez frente a incertidumbres endógenas.

El proceso decisional planteado se articula mediante una serie de interacciones entre los usuarios y el dispositivo lógico de la herramienta VisualUVAM, implementadas mediante el uso de atécnicas de análisis visual y análisis cluster, que han sido ilustradas a través de un ejercicio práctico. En este, la herramienta ofrece alternativas de evaluación de la vulnerabilidad urbana (VU) en España, con un enfoque particularizado en la provincia de Valencia, y culmina con la selección de un modelo de evaluación.

Sobre esta base, una segunda herramienta decisional propone planes de actuación en infraestructura (PAIs) encaminados a mejorar, al menor coste, los niveles de vulnerabilidad de los diferentes grupos de interés representados. Estos planes de actuación, a su vez, son evaluados en base a los riesgos y oportunidades que presentan frente a un conjunto de escenarios relevantes, delimitados de forma dinámica por los decisiores a partir del conjunto de escenarios posibles, generados mediante el módulo D-ROSE. Este método hace explícitas las consecuencias derivadas de la incertidumbre que rodea al problema decisional planteado, y permite identificar alternativas robustas frentre a escenarios negativos que sean a la vez sensibles a los positivos.

Dado que la investigación plantea mejorar los niveles de VU mediante planes integrales de infraestructura urbana, el sistema decisional desarrollado centra su estudio en la incertidumbre relacional que aparece al implementar estos planes a través de las diferentes capas político-administrativas de un sistema multi-escala. El método MS-ReRO evalúa los riegos y oportunidades asociados a un eventual sistema relacional, articulado mediante contratos relacionales, que se propone como marco de coordinación entre entidades de las diferentes escalas del sistema. El proceso decisional desarrollado incorpora este método para proponer, como medidas de acompañamiento político-administrativas, sistemas relacionales que ofrezcan un balance adecuado de los riesgos y oportunidades asociados a la implementación de un determinado plan de acción.

De este modo, la investigación alcanza el objetivo principal planteado y, como se ha discutido en el capítulo anterior, da respuesta a las preguntas de investigación formuladas.

7.1.1 Conclusiones Generales

- Todo MEVU debe incorporar, para resultar acorde con las útimas tendencias en materia de planificación estratégica urbana, los siguientes atributos: ser robustos frente a la incertidumbre, ser participativos como medio de incorporar las percepciones subjetivas de los interesados, considerar la naturaleza dinámica de la VU en sus escalas tanto temporal como político-administrativa, abordar multiples objetivos para mejorar la capacidad estratégica, e implementar procesos cognitivos como forma de potenciar enfoques discursivos.

- En contraste con los atributos de robustez frente a la incertidumbre o de empleo de procesos participativos, el reconocimiento de la naturaleza dinámica de la VU a lo largo tanto del tiempo como de las múltiples escalas que la componen son lineas de investigación que permanecen prácticamente inexploradas.

- Partiendo de los criterios básicos considerados por el Observatorio de Vulnerabilidad Urbana, el modelo decisional diseñado permite seleccionar alternativas con buen comportamiento en relación a los atributos de reconocimiento de la dinámica temporal, ajuste estadístico multi-escala y robustez, a costa de un comportamiento aceptable medio en el objetivo de coincidencia con las preferencias de los profesionales involucrados, respectivamente. Estas preferencias, por otro lado, otorgan más importancia a aspectos diferentes de los considerados por el Observatorio, lo cual sugiere revisar la idoneidad de estos indicadores y emprender la búsqueda de un conjunto alternativo de indicadores básicos.

- La integración de la evaluación de VU dentro de la planificación estratégica urbana, contribuye a mejorar los niveles de vulnerabilidad de un territorio. Un diseño apropiado de alternativas de planificación de acuaciones en infraestructura conduce, para el modelo de caracterización seleccionado, a una mejor contribución de la infraestructura de un territorio a reducir sus niveles de VU. El sistema decisional desarrollado identifica alternativas de este tipo y, mediante el método D-ROSE, que a la vez presenten un buen balace de riesgos y oportunidades frente a la incertidumbre.

- La descentralización de un sistema se puede regular para actuar sobre la incertidumbre relacional que conlleva. Mediante la regulación tanto vertical como horizontal de los derechos conferidos en los diferentes contratos relacionales que articulan el sistema relacional planteado en el módulo MS-ReRO, es posible identificar aquellas políticas de acompañamiento que ofrecen mejores perspectivas a la implementación de un determinado plan de acción a través de un sistema multi-escala.

7.1.2 Conclusiones Específicas

- El empleo de enfoques biofísicos e integrales promueven la progresión en el campo de la evaluación de VU hacia estados evolutivos más avanzados.

Existe un creciente interés en el empleo de métodos de evaluación de la vulnerabilidad en sistemas de infraestructura tanto bajo tierra como en superficie frente a fallos por mal funcionamiento o por colapso. Dentro del capítulo de infraestructura en superficie, aquellas destinadas a hacer frente a inundaciones, como consecuencia del cambio climático, merece una especial atención por el elevado número de investigaciones que la han tratado.

- El análisis de la información cualitativa recabada ha servido para evaluar las preferencias relativas del conjunto de indicadores utlilizados para caracterizar la VU. Estos resultados señalan diferencias muy acusadas en la importancia tanto entre indicadores, como entre los aspectos en los que estos se agrupan, lo cual debe ser considerado a la hora de evaluar el nivel de VU. Para los expertos consultados, los indicadores más relevantes por orden de prioridad son la densidad de población (habitantes por hectárea), la densidad de viviendas (Viv/Ha), el porcentaje de ancianos de 75 años y más (%), y el porcentaje de hogares unipersonales de mayores de 64 años (%). A nivel de aspectos, los más importantes son la Estructura Social, y el Aprovechamiento de Viviendas.

- El empleo conjunto de técnicas de análisis visual y análisis cluster reduce el denominado problema de dimentionalidad característico de los procesos de optimización multi-onjetivo. Por un lado, las técnicas de análisis visual permiten acotar el espacio de soluciones en función a de los niveles de satisfación mínima que se requiera para cada objetivo. Por otro lado, el análisis cluster sintetiza el número de soluciones en un conjunto manejable y representativo de estas en función del objetivo que se considere prioritario.

- El empleo conjunto de aproximaciones bottom-up y top-down en el proceso decisional diseñado, hace posible un análisis de las altertativas tanto desde el punto de vista de las características que las originan, como de los resultados que producen. Mediante el enfoque top-down, se puede observar la dispersión de las diferentes posiciones en el ranking de cada entidad en función del conjunto de modelos de evaluación utilizados. Esta información permite hacerse una idea de la variabilidad del modelo decisional para una determinada entidad de interés, y con ello de la robustez de esta última respecto del conjunto de los modelos alternativos de evaluación.

- El MEVU seleccionado muestra cómo, en el caso de la provincia de Valencia, su estado de vulnerabilidad es mejor y peor que los de Alicante y Castellón, respectivamente. Por otro lado, su evolución ha sido la mejor en su región presentando, además, el menor riesgo de incrementar su vulnerabilidad.

- Esta contextualización tiene lugar así mismo en el resultado de la evaluación cuantitativa de la probabilidad de una entidad a incrementar su vulnerabilidad. Según el modelo de evaluación seleccionado en el estudio de caso, aquellas provincias que se encuentran en regiones que incrementaron su vulnerabilidad en el pasado, son más propensas a pasar a ser más vulnerables en el futuro, lo cual pone de manifiesto en este caso la dependencia del riesgo de vulnerabilidad con respecto del contexto.

- La incorporación de diferentes grupos de interés en la evaluación de las alternativas de planificación permitió identificar la alineación, en lo relativo a impacto sobre la vulnerabilidad, entre los intereses globales y del grupo que presenta mejores oportunidades. Paa el caso del grupo de entidades más vulnerables, no se observa que el impacto sobre estas guarde relación con el impacto sobre los demás grupos de interés. Si que guarda, sin embargo, relación directa con el coste global de las alternativas.

- Las alternativas con un mejor resultado en su evaluación respecto de un determinado objetivo, no tienen porqué ofrecer un mejor balance de riesgos. La alternativa que, en el estudio de caso desarrollado, presentaba un mejor comportamiento para el objetivo de coste global (más barata), presentaba a su vez un balance malo de riesgos y oportunidades frente al conjunto inicial de escenarios y al contrario: la alternativa más cara ofrecía el mejor balance. Sin embargo, a la hora de hacer frente al conjunto de escenarios relevantes, compuesto por los peores y mejores a partir de los umbrales seleccionados por el decisor, la alternativa que presenta un mejor balance entre escenarios vulnerables y resilientes es un plan diferente, con un comportamiento medio-bueno en el objetivo de coste. Esta situación hace patente la dependencia del resultado de la evaluación de incertidumbre, con los umbrales elegidos para determinar qué escenarios resultan relevantes. En conseciencia, el empleo de métodos como el propuesto resulta obligado para evaluar el grado de conveniencia de diferentes estrategias a la hora de hacer frente y aprovechar escenarios especialmente negativos o positivos respectivamente.

- Una parte importante de los sistemas relacionales generados por el módulo MS-ReRO presentan una probabilidad relacional de fallo igual a la probabilidad total de fallo frente a la incertidumbre relacional, por lo que para esos casos, la totalidad del riesgo proveniente de la incertidumbre relacional inherente al sistema de infraestructuras estudiado queda evaluado dentro del sistema relacional propuesto.

- La relación entre las probabilidades de fallo y de beneficio extra es débil e inversa pero no lineal, haciendo posible identificar soluciones que presentan un comportamiento cercano al mejor para ambos criterios.

7.1.3 Limitaciones y líneas de investigación futuras

A pesar de las aportaciones señaladas, el método desarrollado a lo largo de esta investigación aún presenta limitaciones, cuya superación abre la puerta a diversas mejoras.

El método de caracterización empleado parte de la base fijada en el Observatorio de VU, que establece una clasificación básica de las entidades en Vulnerables o No Vulnerables en base a la superación del valor de referencia en alguno de los tres indicadores básicos considerados. Sin embargo, los resultados de esta investigación señalan la importancia de otras variables, y sugieren la revisión de estos indicadores básicos.

Por otro lado, resulta conveniente testar el empleo de otros clasificadores en el modelo de evaluación de VU, como SVM o Naïve Bayes networks, para mejorar la precision del proceso de evaluación. En linea con lo anterior, la exploración de empleo de correlaciones espaciales puede brindar una contribución importante como técnica con la que reforzar la modelización actual de la dependencia contextual de la VU. Así mismo, el proceso de caracterización contine una version básica de control dinámico a lo largo del tiempo, cuya mejora conviene abordar en trabajos futuros. En este sentido, la incorporación de métodos similares a DAPP en la evaluación de alternativas de planificación, aparece como una posibilidad factible de evaluar su comportamiento frente a las variables dinámicas que puedan encontrarse dentro de un period determinado de tiempo.

En cuanto al método D-ROSE, cabe señalar que este ofrece relaciones entre las variables de incertidumbre analizadas, y el comportamiento de las alternativas frente a esta incertidumbre, ya sea relacional o de cualquier otro tipo. Dicha información permitiría la construcción de narativas de escenarios, ofreciendo así la posibilidad de evaluar posibles relaciones causales.

Por otro lado, el sistema decisional está configurado para evaluar incertidumbre relacional exclsuivamente, cuando hay otras que también afectan a la selección de alternativas. La incorporación, por tanto, de incertidumbres provenientes de otras fuentes es una asignatura pendiente, para la que el método D-ROSE ofrece el soporte necesario, y que por lo tanto puede ser acometida ajustando el proceso a los condicionantes de un proceso decisional real.

En relación a esto último, cabe recordar que los resultados obtenidos a lo largo del proceso son más consecuencia de un ejercicio para ilustrar la funcionalidad del proceso, que de una investigación específicamente dirigida a la obtención de planes de infraestructura urbana listos para su implementación por parte de un determinado gobierno, lo cual hubiera requerido de la participación de los decisores correspondientes. En este sentido, una encuesta más ámplia supliría el relativamente bajo núnero de juicios de expertos recopilados para la elaboración de preferencias sujetivas, y serviría para obtener valores más representativos. Igualmente, es necesario un consenso amplio sobre qué conjunto de alternativas de infraestructura deben servir de base a la construcción de alternativas de planificación.

Dada la ingente cantidad de información disponible sobre infraestructura urbana, y la relevancia conferida por la UE a la necesidad de mitigar el problema de la VU la consecución de este último objetivo a través de una apropiada planificación de la infraestructura urbana parece una buena motivación para superar las limitaciones señaladas desarrollando el sistema decisional planteado a través de su aplicación a lo largo de un proceso decisional real.

Conclusions

7.2 Conclusions

The investigation carried out attempts evaluating and addressing urban vulnerability by means of a decisional model aligned with the current trend in the field of urban strategic planning. This study identified several key attributes, defing current urban strategic planning, as a prior step in the development of an integrative decisional tool. In this latter, the decision-makers can evaluate a set of viable assessment models built upon the quantitative and qualitative information gathered. The analysts, as well, are enabled to choose alternatives that meet a proper balance between the objectives of goodness of fit, preferences of stakeholders and robustness against endogenous uncertainties.

The decisional tool, operated by means of interactions between the decision-makers and the logical device, is illustrated by means of a case study. Applied to Spain, the framework generates assessment alternatives for modelling urban vulnerability in this country, with a special focus on the province of Valencia, and supports the decision-makers in the selection of a preferred assessment model.

Based on the above, the decisional system proposes urban infrastructure plans which, at the best cost, best contribute ameliorating urban vulnerability of the different groups of interest identified. These plans are in turn evaluated in terms of the risks and opportunities arisen when facing a set of relevant scenarios, generated and selected through the D-ROSE module. This method builds scenarios to model the uncertainty surrounding the problem, and allows identifying alternatives that are robust against negative scenarios while being sensitive to positive ones.

Since the aiming of the investigation includes the improvement of urban vulnerability by means of integral infrastructure planning, which needs to be implemented across multiple political-administrative layers, the decision support system developed addresses this issue by means of the MS-ReRO method. This thecnique appraises risks and opportunities attached to a given relational system, built upon relational contracts between entities hierarchically linked, which is proposed as a framework for the coordination of these entities. The decisional process developed makes use of this method to propose, policy measures, relational systems whith a proper balance of the risks and opportunities arising from the implementation of a selected planning alternative throughout a multi-scale environment.

This way, the main objective is attained by the investigation which, in the previous chapter, also answers the research questions formulated.

7.2.1 General conclusions

- Accordingly to current urban strategic planning, urban vulnerability assessment models must embody the following attributes: increase of robustness, for dealing with uncertainty, embodiment of participatory processes to grasp subjectivity, consideration of the multiscale and complex nature of the subject as well as its dynamic character, account for multiple objectives to gain strategic capacity and to implement cognitive outlooks.

- In contrast with the attributes of robustness or participative, the recognition of urban vulnerbility's dynamic character trough both time and socio-politial scales are still heavily under-researched areas.

- Following the basic criteria accepted by the Spanish observatory of urban vulnerability, the decisional system allows choosing assessment alternatives bewaving well in time dynamics and multi-scale goodness of fit attributes, at the expense of a bad to medium performance on those of robustness against endogenous uncertainties and proximity to pratitioners' preferences. In these latter, on the other hand, importance is unevenly distributed, and mainly bestowed on to criteria different than those considered by the observatory of vulnerability for the discrimination of entities in vulnerable or not vulnerable. This suggest a need for revising current basic criteria by searching a more appropriate set of indicators.

- A proper design of planning alternatives leads to the improvement in the contribution of a terrotiry's infrastructure system towards alleviating its urban vulnerability. By making use of the D-ROSE method, the decision support system developed finds out alternatives not only meeting this objective, but also presenting a good trade-off between risks and opportunities arisen from uncertainty.

- As well, by both a vertical and horizontal regulation of the rights transferred through the different relational contracts that articulate the relational system proposed in the MS-ReRO module, the decisional framework affords accompanying political-administrative measures showing the better prospects to suscesfully convey a course of action across a multi-scale infrastructure system.

7.2.2 Specific Conclusions

- The employment of approaches from the biophysical and comprehensive schools of though promotes advancing the develpmental stage of urban vulnerability assessment methods.

- There is a groing interest in methods for evaluating vulnerability of both underground and surface infrastructure systems in the case of failure due to malfunctions or breackdown. Among the class surface infrastructure systems, those intended to prevent waterflood produced by climate change deserves special attention due to the amount of studies addressing this issue.

- From the analysis of the qualitative information gathered on pratitioners' preferences regarding indicators to be used for the assement of urban vulnerability, it can be stated that there are huge differences in importance between these indicators, which has to be considered when assessing vulnerability. The most relevant indicators, from expert judgment, are density of population (pop/ha), density of dwellings (dwe/ha), population older than 75 years (%), and households of one adult and at least one minor (%). As to the aspects, those regarding social structure and Dwellings size are the most important.

- The joint use of techniques of visual analysis and cluster analysis reduces the so-called “curse of dimensionality” problem, characteristic of multi-onjetive optimization processes. On the one hand, visual analysis enables decision-makers to delimitate the space of solutions accordingly to their requirements for each objective. This, together with the usage of clustering methods, allows the user sinthesising solutions, which otherwise would be unmanageable, in an affordable number of them.

- The characterization method takes advantage of the joint use of bottom-up and top-down approaches in the decisional process, allowing an analysis of the alternatives from the point of view of the characteristics that originate them, as well as from the results they produce. Through the top-down approach, the user can appreciate, for a given entity, the dispersion of positions in the ranking for the different evaluation models. This information allows us to get an idea of the variability, throughout the decision space, of any entity of interest, and to establish a range of more likely values based on the set of evaluation alternatives considered.

- The methodology proposed affords valuable insight for contextualizing entities. The selected UVA model shows how, for example, the province of Valencia’s state of vulnerability is better and worse that that of Alicante and Castellon respectively. Its evolution, on the other hand, has been the best in its region, while at the same time presents the least risk of increasing its vulnerabilily. This contextualization is also effecive in the quantitative evaluation used to determine entities’ probability to become more vulnerable. For the selected UVA model, provinces in regions that in the past increased its vulnerability, makes them prone for becoming more vulnerable in the future, which reveal the relationship between entities’ vulnerability and their context.

- By taking into account different groups of interest, the decision system made it possible to identify the convergence between the overall and the opportunity groups as regards impacts on vulnerability of these groups. This, however, cannot be applied to the most vulnerable group, which shows no linkage with the other two groups, while being directly related to the overall cost objective.

- Alternatives performing best regarding a given objective does not necessarily offer a better balance between risks and opportunities associated to that objective. The case study showed how, when considering the whole spectrum of possible scenarios, the alternative presenting the best (cheaper) behaviour on overall cost also presented a poor balance of risks and opportunities and on the contrary, the worst (most expensive) had the better balance. However, when considering the set of relevan scenarios composed by both positive and negative extrem values, the best balance between vulnerability and resilient was no longer the most expensive but a mild one. This revealed the dependence between uncertainty assessment and the thresholds for selecting relevant scenarios, which compels us to make use of methods similar to D-ROSE for the evaluation of alternatives to face or take profit of specially negative or positive scenarios respectively.

- Most of the relational systems generated through the MS-ReRO module presents a relational failure probaiblity equal to the total failure probability, which means that in such cases, all risk arising from the uncertainty attached to the infrastructure system being analyzed, is embraced within the relational systems proposed.

- The relationship between failure and windfall probabilities of relational systems is faint and inverse, and presents high nonlinearities that allows to find out solutions close to the bests for each of these criteria.

7.2.3 Limitations and future research

Despite the contributions rendered by this investigation, the decision support system developed presents several limitations, which overcoming would lead to important improvements

The urban vulnerability assessment models presented are built upon the base laid by the Observatorio de Vulnerabilidad Urbana, which settles a basic classification of entities into vulnerable or not vulnerable attending to the reference values of a set of three basic indicators. The suitability of these indicators, however, has been questioned along this investigation, and as as consequence of this latter further investigation on the proper set of basic indicators is required.

On the other hand, the use of other machine-learning methods such as neural networks, SVM or Naïve Bayes networks, can be tested to obtain more accurate models. Regarding this latter, research on the spatial correlation among entities could disclose valuable information with which to improve the capacity of contextualizing urban vulnerability. In addition, this methodology embodies a basic dynamic control over time and context that should be improved in future research focusing on this issue. In this vein, the implementation of methods such as DAPP could help dealing with time-dependent variables affecting urban planning.

As well, D-ROSE does not analyse relations between the uncertainty variables configuring scenarios and the vulnerable or resilient outcomes, which would enable decision-makers to build narrative scenarios on this basis. This would afford causal relations wich, on the other hand, could mislead decision process due to the so-called narrative fallacie.

Further, the decision support system presented is configured to evaluate risks and opportunities arising from exclusively relational uncertainty. There are, however, other types of uncertainty affecting the selection of infrastructure planning alternatives, which incorporation into the decision process is still pending. Since D-ROSE can deal vith every kind of uncertainty, this implementation is perfectly attainable by reconfiguring the process accordingly to the needings arisen from real decision-making.

Regarding this latter, it has to be borne in mind that the results obtained throughout the process are are the output of an exercise to test the usefulness of the methods presented rather than the outcome of research specifically aimed to produce infrastructure planning candidates ready for being implemented by any government, which would have needed of the participation of the corresponding decision makers. In this sense, a broader survey in order to obtain more representative values.

In this sense, a more extensive survey would supply the relatively low number of expert judgments collected for the elaboration of subjective preferences, and would serve to obtain more representative values. Likewise, a broad consensus is needed on which set of infrastructure alternatives should serve as a basis for the construction of planning alternatives.

Finally, given the vast information available on the state of both point and net urban infrastructures in EU countries, and the relevance of evaluating them under key aspects like urban vulnerability, such undertaking seems a good motivation for the further development of the decision support system presented by addressing its limitations through its application to real decision-making.

Conclusions

7.3 Conclusions

Aquesta investigació explora la possibilitat de plantejar tant models d'avaluació de vulnerabilitat urbana (MEVU), com plans d'actuació amb què fer-la front, alineats amb les últimes tendències en el camp de la planificació estratègica urbana. Al llarg d'aquesta tesi, s'han identificat els criteris clau que defineixen l'avantguarda actual en planificació estratègica com a pas previ al disseny d'una eina de decisió que els integri. En aquesta, el decisor pot avaluar un conjunt de possibles MEVU construïts a partir d'informació tant quantitativa com quantitativa, i seleccionar el que ofereixi el balanç més adequat entre els objectius d'ajust estadístic, alineació amb les preferències dels involucrats i robustesa enfront de incerteses endògenes.

El procés de decisió plantejat s'articula mitjançant una sèrie d'interaccions entre els usuaris i el dispositiu lògic de l'eina, que han estat il·lustrades a través d'un exercici pràctic en el qual s'ofereixen alternatives d'avaluació de la vulnerabilitat urbana (VU) a Espanya, amb un enfocament particularitzat a la província de València, i culmina amb la selecció d'un model d'avaluació.

Sobre aquesta base, una segona eina de decisió proposa plans d'actuació en infraestructura urbana encaminades a millorar, al menor cost, els nivells de vulnerabilitat dels diferents grups d'interès representats. Aquests plans d'actuació, al seu torn, són avaluats en base als riscos i oportunitats que presenten enfront d'un conjunt d'escenaris rellevants, delimitats de forma dinàmica pels decisiores a partir del conjunt d'escenaris possibles, generats mitjançant el mòdul D-ROSE . Aquest mètode fa explícites les conseqüències derivades de la incertesa que envolta el problema de decisió plantejat, i permet identificar alternatives robustes frentre a escenaris negatius que siguin alhora sensibles als positius.

Atès que la investigació planteja millorar els nivells de VU mitjançant plans integrals d'infraestructura urbana, el sistema de presa de decisions desenvolupat centra el seu estudi en la incertesa relacional que apareix en implementar aquests plans a través de les diferents capes politicoadministratives d'un sistema multi-escala. El mètode MS-rero avalua els regs i oportunitats associats a un eventual sistema relacional, articulat mitjançant contractes relacionals, que es proposa com a marc de coordinació entre entitats de les diferents escales del sistema. El procés de decisió desenvolupat incorpora aquest mètode per proposar, com a mesures d'acompanyament politicoadministratives, sistemes relacionals que ofereixin un balanç adequat dels riscos i oportunitats associats a la implementació d'un determinat pla d'acció.

D'aquesta manera, la investigació aconsegueix l'objectiu principal plantejat i, com s'ha discutit en el capítol anterior, dóna resposta a les preguntes de recerca formulades.

7.3.1 Conclusions Generals

- Tot MEVU ha d'incorporar, per a resultar d'acord amb les útimas tendències en matèria de planificació estratègica urbana, els següents atributs: ser robustos davant de la incertesa, ser participatius com a mitjà d'incorporar les percepcions subjectives dels interessats, considerar la naturalesa dinàmica de la VU en les seves escales tant temporal com politicoadministrativa, abordar múltiples objectius per millorar la capacitat estratègica, i implementar processos cognitius com a forma de potenciar enfocaments discursius.

- En contrast amb els atributs de robustesa enfront de la incertesa o d'ocupació de processos participatius, el reconeixement de la naturalesa dinàmica de la VU al llarg tant del temps com de les múltiples escales que la componen són línies de recerca que romanen pràcticament inexplorades .

- Partint dels criteris bàsics considerats per l'Observatori de Vulnerabilitat Urbana, el model de decisió dissenyat permet seleccionar alternatives amb bon comportament en relació als atributs de reconeixement de la dinàmica temportal i ajust estadístic multi-escala, a costa d'un comportament dolent i mig en els objectius de robustesa enfront de incerteses endògenes i de coincidència amb les preferències dels professionals involucrats, respectivament. Aquestes preferències, d'altra banda, atorguen més importància a aspectes diferents dels considerats per l'Observatori, la qual cosa suggereix revisar la idoneïtat d'aquesta selecció emprenent la recerca d'un conjunt alternatiu d'indicadors bàsics.

- Un disseny apropiat d'alternatives de planificació de acuaciones urbanes condueix, per al model de caracterització seleccionat, a una millor contribució de la infraestructura d'un territori a reduir els seus nivells de VU. El sistema de decisió desenvolupat identifica alternatives d'aquest tipus i, mitjançant el mètode D-ROSE, que alhora presentin un bon Balace de riscos i oportunitats davant de la incertesa.

- Així mateix, mitjançant la regulació tant vertical com horitzontal dels drets conferits en els diferents contractes relacionals que articulen el sistema relacional plantejat en el mòdul MS-rero, és possible identificar aquelles polítiques d'acompanyament que ofereixen millors perspectives a la implementació d'un determinat pla d'acció a través d'un sistema multi-escala.

7.3.2 Conclusions Especifiques

- L'ocupació d'enfocaments biofísics i integrals promouen la progressió en el camp de l'avaluació de VU cap a estats evolutius més avançats.

- Hi ha un creixent interès en l'ocupació de mètodes d'avaluació de la vulnerabilitat en sistemes d'infraestructura tant sota terra com en superfície enfront de fallades per mal funcionament o per col·lapse. Dins el capítol d'infraestructura en superfície, aquelles destinades a fer front a inundacions, com a conseqüència del canvi climàtic, mereix una especial atenció per l'elevat nombre d'investigacions que l'han tractat.

- L'anàlisi de la informació qualitativa recollida ha servit per avaluar les preferències relatives del conjunt d'indicadors utlilizados per caracteritzar la VU. Aquests resultats assenyalen diferències molt acusades en la importància tant entre indicadors, com entre els aspectes en què aquests s'agrupen, la qual cosa ha de ser considerat a l'hora d'avaluar el nivell de VU. Per als experts consultats, els indicadors més rellevants per ordre de prioritat són la densitat de població (habitants per hectàrea), la densitat d'habitatges (Viv / ha), el percentatge de gent gran de 75 anys i més (%), i el percentatge de llars unipersonals de majors de 64 anys (%). A nivell d'aspectes, els més importants són l'Estructura Social, i l'Aprofitament d'Habitatges.

- L'ús de filtres permet acotar l'espai de solucions en funció a dels nivells de satisfacció mínima que es requereixi per a cada objectiu. Això, juntament amb l'ús de tècniques clúster, permet sintetitzar el nombre de solucions en un conjunt manejable d'aquestes en funció de l'objectiu que es consideri prioritari.

- L'ocupació conjunt d'aproximacions bottom-up i top-down en el procés de decisió dissenyat, fa possible una anàlisi de les altertativas tant des del punt de vista de les característiques que les originen, com dels resultats que produeixen. Mitjançant l'enfocament top-down, es pot observar la dispersió de les diferents posicions en el rànquing de cada entitat en funció del conjunt de models d'avaluació utilitzats. Aquesta informació permet fer-se una idea de la variabilitat del model de decisió per a una determinada entitat d'interès, i amb això de la robustesa d'aquesta última respecte del conjunt dels models alternatius d'avaluació.

- El MEVU seleccionat mostra com, en el cas de la província de València, el seu estat de vulnerabilitat és millor i pitjor que els d'Alacant i Castelló, respectivament. D'altra banda, la seva evolució ha estat la millor en la seva regió presentant, a més, el menor risc d'incrementar la seva vulnerabilitat.

- Aquesta contextualització té lloc així mateix en el resultat de l'avaluació quantitativa de la probabilitat d'una entitat a incrementar la seva vulnerabilitat. Segons el model d'avaluació seleccionat en l'estudi de cas, aquelles províncies que es troben en regions que van incrementar la seva vulnerabilitat en el passat, són més propenses a passar a ser més vulnerables en el futur, la qual cosa posa de manifest en aquest cas la dependència del risc de vulnerabilitat respecte del context.

- La incorporació de diferents grups d'interès en l'avaluació de les alternatives de planificació va permetre identificar l'alineació, pel que fa a impacte sobre la vulnerabilitat, entre els interessos globals i del grup que presenta millors oportunitats. Paa el cas del grup d'entitats més vulnerables, no s'observa que l'impacte sobre aquestes guardi relació amb l'impacte sobre els altres grups d'interès. Si que guarda, però, relació directa amb el cost global de les alternatives.

- Les alternatives amb un millor resultat en la seva avaluació respecte d'un determinat objectiu, no tenen perquè oferir un millor balanç de riscos. L'alternativa que, en l'estudi de cas desenvolupat, presentava un millor comportament per a l'objectiu de cost global (més barata), presentava al seu torn un balanç dolent de riscos i oportunitats davant del conjunt inicial d'escenaris i al contrari: l'alternativa més cara oferia el millor balanç. No obstant això, a l'hora de fer front al conjunt d'escenaris rellevants, compost pels pitjors i millors a partir dels llindars seleccionats pel decisor, l'alternativa que presenta un millor balanç entre escenaris vulnerables i resilients és un pla diferent, amb un comportament mitjà-bo en l'objectiu de cost. Aquesta situació fa palesa la dependència del resultat de l'avaluació d'incertesa, amb els llindars elegits per a veure els escenaris resulten rellevants. En conseciencia, l'ús de mètodes com el proposat resulta obligat per avaluar el grau de conveniència de diferents estratègies a l'hora de fer front i aprofitar escenaris especialment negatius o positius respectivament.

- Una part important dels sistemes relacionals generats pel mòdul MS-rero presenten una probabilitat relacional de fallada igual a la probabilitat total de fallada davant de la incertesa relacional, de manera que per a aquests casos, la totalitat del risc provinent de la incertesa relacional inherent al sistema d'infraestructures estudiat queda avaluat dins el sistema relacional proposat.

- La relació entre les probabilitats de fallada i de benefici extra és feble i inversa però no lineal, fent possible identificar solucions que presenten un comportament proper al millor per a tots dos criteris.

7.3.3 Limitacions i línies de recerca futures

Tot i les aportacions assenyalades, el mètode desenvolupat al llarg d'aquesta investigació encara presenta limitacions, la superació obre la porta a diverses millores.

El mètode de caracterització emprat parteix de la base fixada a l'Observatori de VU, que estableix una classificació bàsica de les entitats en Vulnerables o No Vulnerables sobre la base de la superació del valor de referència en algun dels tres indicadors bàsics considerats. No obstant això, els resultats d'aquesta investigació assenyalen la importància d'altres variables, i suggereixen la revisió d'aquests indicadors bàsics.

D'altra banda, resulta convenient testar l'ocupació d'altres classificadors en el model d'avaluació de VU, com SVM o Naïve Bayes networks, per millorar la precisió del procés d'avaluació. En línia amb l'anterior, l'exploració d'ocupació de correlacions espacials pot oferir una contribució important com tècnica amb la qual reforçar la modelització actual de la dependència contextual de la VU. Així mateix, el procés de caracterització contine una versió bàsica de control dinàmic al llarg del temps, la millora convé abordar en treballs futurs. En aquest sentit, la incorporació de mètodes similars a DAPP en l'avaluació d'alternatives de planificació, apareix com una possibilitat factible d'avaluar el seu comportament enfront de les variables dinàmiques que puguin trobar-se dins d'un Període determinat de temps.

Pel que fa al mètode D-ROSE, cal assenyalar que aquest ofereix relacions entre les variables d'incertesa analitzades, i el comportament de les alternatives davant d'aquesta incertesa, ja sigui relacional o de qualsevol altre tipus. Aquesta informació permetria la construcció d'narativas d'escenaris, oferint així la possibilitat d'avaluar possibles relacions causals.

D'altra banda, el sistema de presa de decisions està configurat per avaluar incertesa relacional exclsuivamente, quan evidentment hi ha altres que també afecten la selecció d'alternatives. La incorporació, per tant, d'incerteses provinents d'altres fonts és una assignatura pendent, per la qual el mètode D-ROSE ofereix el suport necessari, i que per tant pot ser escomesa ajustant el procés als condicionants d'un procés de decisió real.

En relació a això últim, cal recordar que els resultats obtinguts al llarg del procés són mes conseqüència d'un exercici per il·lustrar la funcionalitat del procés, que d'una investigació específicament dirigida a l'obtenció de plans d'infraestructura urbana llestos per a la seva implementació per part d'un determinat govern, la qual cosa hagués requerit de la participació dels decisors corresponents. En aquest sentit, una enquesta més àmplia supliria el relativament baix número de judicis d'experts recopilats per a l'elaboració de preferències subjectives, i serviria per obtenir valors més representatius. Igualment, cal un consens ampli sobre quin conjunt d'alternatives d'infraestructura han de servir de base a la construcció d'alternatives de planificació.

Donada la ingent quantitat d'informació disponible sobre infraestructura urbana, i la rellevància conferida per la UE a la necessitat de mitigar el problema de la VU la consecució d'aquest últim objectiu a través d'una apropiada planificació de la infraestructura urbana sembla una bona motivació per superar les limitacions assenyalades desenvolupant el sistema de decisió plantejat a través de la seva aplicació al llarg d'un procés de decisió real.

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ANEXOS

Anexo 1
Portadas de los artículos publicados

Anexo 1.1: Portada del articulo *Urban vulnerability assessment: Advances from the strategic planning outlook*, publicado en Journal of Cleaner Production (Capítulo 2)
DOI: *https://doi.org/10.1016/j.jclepro.2017.11.249*

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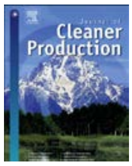

Review

Urban vulnerability assessment: Advances from the strategic planning outlook

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Vulnerability assessment
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a b s t r a c t

Urban strategic planning and urban vulnerability assessment have increasingly become important issues in both policy agenda and academia. However, a comprehensive review of the advances made in urban vulnerability, emphasizing their shared aspects, has yet to be performed. The aiming of this paper is to addresses the latter by conducting an evaluation on assessment methods disclosed in this decade. Once their common evolutive pathway is traced, the review follows an analytical framework, based on the above, evaluating the research requirements from both a quantitative and qualitative point of view. Our findings indicate that the robustness, cognitive and participatory research lines are those in which most advancement has been made, while those of urban dynamics and multi-scale progressed the least. Our analysis also demonstrates that methods integrating more lines of research, as well as the employment of comprehensive approaches, promotes advancing the developmental stage. We conclude that the focusing of research lines should be shifted, in order to bridge the qualitative gap identified without demanding an improbable, quantitative increase.

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Anexo 1.2: Portada del articulo *A discursive, many-objective approach for selecting more-evolved urban vulnerability assessment models*, publicado en Journal of Cleaner Production (Capítulo 3)
DOI: *https://doi.org/10.1016/j.jclepro.2017.11.249*

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A discursive, many-objective approach for selecting more-evolved urban vulnerability assessment models

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a r t i c l e i n f o

Article history:
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Keywords:
Urban vulnerability assessment
Discursive approach
Many-objective optimization
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a b s t r a c t

The development of more-evolved urban vulnerability assessment (UVA) models has become an increasingly important issue for both policy agendas and academia. Several requirements have already been set for this goal; they should be pursued simultaneously. However, methods with such integration are yet to be developed. The present paper addresses this integration via a discursive process in which interactions between decision makers and the method contribute to the selection of a model fulfilling these requirements. That model yields a UVA built upon both qualitative information and quantitative data from indicators selected for the neighbourhood, city, province, region and country political-administrative scales. The characteristics demanded are encoded both into the UVA assessment model and in the optimization and control modules governing the process. While the optimization produces compromise solutions, the control module supervises the process, provides dynamic control and enables the interactions. Interactions are informed with knowledge derived from the cognitive approach entailed by the method and afford a better understanding of the process dynamics. We conclude that the goodness of fit and time dynamics objectives are aligned. Therefore, UVA methods performing well for these objectives are available, although at the expense of a medium to poor performance in preferences and robustness

1. Introduction

Urban vulnerability (UV) in general and its adaptive component in particular have become key issues for urban strategic planning (USP) (Rigillo and Cervelli, 2014) with the aim of achieving sustainable development (Malekpour et al., 2015) and coping with climate change (McCarthy et al., 2001; Turner et al., 2003; Adger, 2006; Chang and Huang, 2015). Specifically, improvements of adaptive governance and strategic planning in the context of climate change and socio-economic transformation are demanded (Birkmann et al., 2014). As a consequence, methods that assess vulnerability are increasingly being developed for countries around the world (Fekete, 2009).

The IPCC Assessment Report (McCarthy et al., 2001) defines vulnerability as follows:

> "The degree to which a system (entity) is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity."

Nevertheless, there are many other definitions that challenge current thinking, to the extent that it is necessary to perform research specifically aimed at conceptual clarification (Füssel and Klein, 2006; Wolf et al., 2013), which exceeds the scope of this study. A few aspects, however, are beyond question, the first being that vulnerability should be assessed with regard to not only its current state alone but also its future risk, and the other being the attributes demanded by the research community for the assessment of this concept.

Concerning the first aspect, several authors have pointed out the dynamic character of vulnerability over time and that, in consequence, along with the current state of vulnerability, the risk of becoming (more) vulnerable also needs to be measured (Adger, 2006; Birkmann et al., 2014; Füssel, 2007; Nahiduzzaman et al.,

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Anexo 1.3: Portada del articulo *MS-ReRO and D-ROSE methods: assessing relational uncertainty and evaluating scenarios' risks and opportunities on multi-scale infrastructure systems*, publicado en Journal of Cleaner Production (Capítulo 5)
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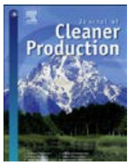

A discursive, many-objective approach for selecting more-evolved urban vulnerability assessment models

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a r t i c l e i n f o

Article history:
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Keywords:
Urban vulnerability assessment
Discursive approach
Many-objective optimization
Cognitive approach

a b s t r a c t

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Results of the analysis at the regional, provincial and municipal levels

Escala	ID	Nombre	Ent. Sup	Riesgo (val)	Ranking Absoluto Riesgo	Ranking Absoluto Estado	Ranking Absoluto Evol Est.	Ranking Relativo Riesgo	Ranking Relativo Estado	Ranking Relativo Evol Est.
region	ESA	ANDALUCÍA	1	-3.71E-43	7	19	0	7	19	0
	ESB	Aragón	2	10,584	18	9	1	18	9	1
	ESC	Asturias	3	-3.06E-49	8	7	0	8	7	0
	ESD	Balears	4	-30,079	1	6	-3	1	6	-3
	ESE	Canarias	5	-0.9889	6	10	-1	6	10	-1
	ESF	Cantabria	6	3.27E-90	11	5	0	11	5	0
	ESG	Castilla y León	7	0.9733	13	16	1	13	16	1
	ESH	Castilla-La Mancha	8	-10,307	2	15	-1	2	15	-1
	ESI	Cataluña	9	10,046	16	18	1	16	18	1
	ESJ	Comunidad Valenciana	10	-10,038	3	17	-1	3	17	-1
	ESK	Extremadura	11	-0.9942	4	12	-1	4	12	-1
	ESL	Galicia	12	4.74E-78	12	14	0	12	14	0
	ESM	Madrid	13	10,116	17	13	1	17	13	1
	ESN	Murcia	14	0.9868	15	11	1	15	11	1
	ESO	Navarra	15	3.38E-98	9	4	0	9	4	0
	ESP	País Vasco	16	19,688	19	8	2	19	8	2
	ESQ	Rioja (La)	17	1.60E-97	10	3	0	10	3	0
	ESR	Ceuta	18	0.9858	14	2	1	14	2	1
	ESS	Melilla	19	-0.9896	5	1	-1	5	1	-1
provincias	ESA11	Cádiz	11	18,054	51	52	5	7	8	2
	ESA14	Córdoba	14	-0.8263	3	42	4	1	3	-2
	ESA18	Granada	18	-0.0937	12	39	5	4	2	-1
	ESA21	Huelva	21	-0.0082	21	44	8	5	5	1
	ESA23	Jaén	23	-0.6114	5	37	4	2	1	-1
	ESA29	Málaga	29	0.0477	39	48	-1	6	6	-1
	ESA4	Almería	4	19,542	52	43	14	8	4	3
	ESA41	Sevilla	41	-0.3652	8	50	0	3	7	-1
	ESB22	Huesca	22	1.34E+00	29	5	1	2	2	0
	ESB44	Teruel	44	0.0011	33	2	0	3	1	0
	ESB50	Zaragoza	50	-0.9830	2	19	-11	1	3	0
	ESC33	Asturias	33	0.0032	35	27	-8	1	1	0
	ESD38	Santa Cruz de Teneri	38	0.1666	46	47	4	2	2	1
	ESD7	Balears	7	-0.0358	16	34	-10	1	1	-1
	ESE35	Palmas (Las)	35	0.0030	34	49	4	1	1	0
	ESE39	Cantabria	39	0.0791	41	21	-7	1	1	0
	ESG24	León	24	-0.6944	4	8	-9	1	6	-2
	ESG34	Palencia	34	-0.0014	25	4	-3	5	3	0

Escala	ID	Nombre	Ent. Sup	Riesgo (val)	Ranking Absoluto Riesgo	Ranking Absoluto Estado	Ranking Absoluto Evol Est.	Ranking Relativo Riesgo	Ranking Relativo Estado	Ranking Relativo Evol Est.
	ESG37	Salamanca	37	0.5924	48	15	1	8	8	1
	ESG40	Segovia	40	-0.0019	24	3	0	4	2	0
	ESG42	Soria	42	-0.0863	13	1	0	3	1	0
	ESG47	Valladolid	47	-0.1997	10	17	-8	2	9	0
	ESG49	Zamora	49	8.51E+00	32	6	-3	6	4	0
	ESG5	Ávila	5	0.7592	49	11	1	9	7	2
	ESG9	Burgos	9	0.0480	40	7	-6	7	5	-1
	ESH13	Ciudad Real	13	-0.3154	9	24	1	2	4	0
	ESH16	Cuenca	16	16,542	50	16	10	5	2	1
	ESH19	Guadalajara	19	-11,408	1	12	4	1	1	-1
	ESH2	Albacete	2	-0.0476	15	23	3	3	3	0
	ESH45	Toledo	45	0.0053	36	28	4	4	5	0
	ESI17	Girona	17	-0.0194	18	29	-2	1	2	0
	ESI25	Lleida	25	-8.74E+00	26	9	-2	2	1	0
	ESI43	Tarragona	43	0.0923	42	32	0	4	3	0
	ESI8	Barcelona	8	0.0319	38	38	-13	3	4	0
	ESJ12	Castellón/Castelló	12	0.0146	37	26	0	2	1	0
	ESJ3	Alicante/Alacant	3	0.1194	43	41	-5	3	3	1
	ESJ46	Valencia/València	46	-0.3838	7	36	-12	1	2	-1
	ESK10	Cáceres	10	-1.10E+00	27	30	8	2	1	0
	ESK6	Badajoz	6	-0.0559	14	33	-6	1	2	0
	ESL15	Coruña (A)	15	2.38E+00	30	31	-6	4	3	0
	ESL27	Lugo	27	-0.0028	23	14	-2	2	1	0
	ESL32	Ourense	32	-0.0292	17	22	3	1	2	0
	ESL36	Pontevedra	36	1.13E+00	28	35	-5	3	4	0
	ESM 28	Madrid	28	0.1436	45	40	-12	1	1	0
	ESN30	Murcia	30	-0.0063	22	45	3	1	1	0
	ESO31	Navarra	31	2.40E+00	31	13	-14	1	1	0
	ESP 1	Álava	1	-0.5653	6	18	-3	1	1	-1
	ESP20	Guipúzcoa	20	0.3156	47	20	2	3	2	1
	ESP48	Vizcaya	48	-0.0126	20	25	-16	2	3	0
	ESQ26	Rioja (La)	26	-0.1643	11	10	5	1	1	0
	ESR51	Ceuta	51	-0.0152	19	51	36	1	1	0
	ESS52	Melilla	52	0.1281	44	46	34	1	1	0
Ciudades	46001ESJ	Ademuz	46001	328,505	331	72	3	195	72	3
	46002ESJ	Ador	46002	-602,884	79	75	-111	78	75	-111
	46003ESJ	Atzeneta d?Albaida	46003	-675,716	70	47	-127	69	47	-127
	46004ESJ	Agullent	46004	-0.1967	205	86	-6	156	86	-6

Escala	ID	Nombre	Ent. Sup	Riesgo (val)	Ranking Absoluto Riesgo	Ranking Absoluto Estado	Ranking Absoluto Evol Est.	Ranking Relativo Riesgo	Ranking Relativo Estado	Ranking Relativo Evol Est.
	46005ESJ	Alaquàs	46005	1,108,076	384	174	152	247	174	152
	46006ESJ	Albaida	46006	323,610	330	155	105	194	155	105
	46007ESJ	Albal	46007	868,972	366	168	124	229	168	124
	46008ESJ	Albalat de la Ribera	46008	-34,715	192	108	-24	150	108	-24
	46009ESJ	Albalat dels Sorells	46009	511,099	348	110	4	211	110	4
	46010ESJ	Albalat dels Tarongers	46010	-986,871	41	90	-85	40	90	-85
	46011ESJ	Alberic	46011	896,680	368	150	104	231	150	104
	46012ESJ	Alborache	46012	-1,039,619	35	140	6	34	140	6
	46013ESJ	Alboraya	46013	1,018,102	379	204	180	242	204	180
	46014ESJ	Albuixech	46014	-13,108	202	148	49	154	148	49
	46015ESJ	Alcàsser	46015	447,741	345	142	67	208	142	67
	46016ESJ	Alcàntera de Xúquer	46016	-354,842	115	54	-126	107	54	-126
	46017ESJ	Alzira	46017	1,244,182	389	200	193	252	200	193
	46018ESJ	Alcublas	46018	-1,168,184	22	169	0	22	169	0
	46019ESJ	Alcúdia (l?)	46019	400,586	337	151	91	200	151	91
	46020ESJ	Alcúdia de Crespins (l?)	46020	49,102	305	139	67	174	139	67
	46021ESJ	Aldaia	46021	805,621	362	187	164	225	187	164
	46022ESJ	Alfafar	46022	799,737	361	180	141	224	180	141
	46023ESJ	Alfauir	46023	-1,210,193	17	169	-74	17	169	-74
	46024ESJ	Alfara de Algimia	46024	-1,184,115	20	169	-50	20	169	-50
	46025ESJ	Alfara del Patriarca	46025	44,239	303	102	-11	172	102	-11
	46026ESJ	Alfarp	46026	-588,264	81	84	-54	79	84	-54

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	46027ESJ	Alfarrasí	46027	-446,736	105	65	-93	98	65	-93
	46028ESJ	Algar de Palancia	46028	-1,380,670	9	169	-60	9	169	-60
	46029ESJ	Algemesí	46029	979,884	377	202	181	240	202	181
	46030ESJ	Algimia de Alfara	46030	-733,360	65	94	-88	64	94	-88
	46031ESJ	Alginet	46031	311,763	328	154	93	192	154	93
	46032ESJ	Almàssera	46032	838,324	364	121	37	227	121	37
	46033ESJ	Almiserà	46033	-1,170,555	21	169	-87	21	169	-87
	46034ESJ	Almoines	46034	-842,829	50	70	-102	49	70	-102
	46035ESJ	Almussafes	46035	672,034	354	119	46	217	119	46
	46036ESJ	Alpuente	46036	-1,009,632	39	169	61	38	169	61
	46037ESJ	Alquería de la Condesa/Alqueria de la Comtessa (l?)	46037	-770,397	59	85	-120	58	85	-120
	46038ESJ	Andilla	46038	-447,594	104	169	-33	97	169	-33
	46039ESJ	Anna	46039	-104,120	170	62	-55	138	62	-55
	46040ESJ	Antella	46040	-146,786	155	27	-133	128	27	-133
	46041ESJ	Aras de los Olmos	46041	-565,703	83	169	33	81	169	33
	46042ESJ	Aielo de Malferit	46042	519,672	349	109	30	212	109	30
	46043ESJ	Aielo de Rugat	46043	-1,303,335	12	169	-80	12	169	-80
	46044ESJ	Ayora	46044	414,801	339	133	88	202	133	88
	46045ESJ	Barxeta	46045	47,051	304	33	-115	173	33	-115
	46046ESJ	Barx	46046	-166,746	152	63	-60	125	63	-60
	46047ESJ	Bèlgida	46047	-1,041,270	34	19	-187	33	19	-187

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	46048ESJ	Bellreguard	46048	251,359	323	120	23	188	120	23
	46049ESJ	Bellús	46049	-644,576	75	169	-62	74	169	-62
	46050ESJ	Benagéber	46050	-2,015,067	2	169	-67	2	169	-67
	46051ESJ	Benaguasil	46051	868,075	365	157	119	228	157	119
	46052ESJ	Benavites	46052	-523,908	93	9	-211	89	9	-211
	46053ESJ	Beneixida	46053	-1,129,262	27	28	-212	27	28	-212
	46054ESJ	Benetússer	46054	975,102	376	147	88	239	147	88
	46055ESJ	Beniarjó	46055	-354,753	116	117	-70	108	117	-70
	46057ESJ	Benicolet	46057	-1,167,510	23	36	-212	23	36	-212
	46058ESJ	Benifairó de les Valls	46058	-137,673	159	69	-73	131	69	-73
	46059ESJ	Benifairó de la Valldigna	46059	-94,395	175	89	-55	142	89	-55
	46060ESJ	Benifaió	46060	614,296	352	144	102	215	144	102
	46061ESJ	Beniflá	46061	-1,320,429	11	5	-255	11	5	-255
	46062ESJ	Benigánim	46062	405,091	338	111	44	201	111	44
	46063ESJ	Benimodo	46063	-29,812	194	76	-33	151	76	-33
	46064ESJ	Benimuslem	46064	-625,940	78	37	-167	77	37	-167
	46065ESJ	Beniparrell	46065	-100,595	171	53	-111	139	53	-111
	46066ESJ	Benirredrà	46066	0.4898	292	35	-180	163	35	-180
	46067ESJ	Benisanó	46067	0.8632	295	71	-118	166	71	-118
	46068ESJ	Benissoda	46068	-907,507	46	4	-238	45	4	-238
	46069ESJ	Benisuera	46069	-1,702,218	4	169	-85	4	169	-85
	46070ESJ	Bétera	46070	1,430,933	395	192	172	258	192	172

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	46071ESJ	Bicorp	46071	-787,338	57	169	-21	56	169	-21
	46072ESJ	Bocairent	46072	419,460	341	131	75	204	131	75
	46073ESJ	Bolbaite	46073	-378,948	113	74	-41	106	74	-41
	46074ESJ	Bonrepòs i Mirambell	46074	100,387	311	82	-112	180	82	-112
	46075ESJ	Bufali	46075	-1,027,892	38	169	-55	37	169	-55
	46076ESJ	Bugarra	46076	-1,196,123	19	14	-183	19	14	-183
	46077ESJ	Buñol	46077	508,774	347	185	159	210	185	159
	46078ESJ	Burjassot	46078	1,569,331	398	191	180	261	191	180
	46079ESJ	Calles	46079	-1,085,319	30	169	-12	30	169	-12
	46080ESJ	Camporrobles	46080	-500,048	96	169	38	91	169	38
	46081ESJ	Canals	46081	974,422	375	166	132	238	166	132
	46082ESJ	Canet d?En Berenguer	46082	-0.1067	207	172	39	157	172	39
	46083ESJ	Carcaixent	46083	1,038,699	381	181	150	244	181	150
	46084ESJ	Càrcer	46084	-779,504	58	104	-75	57	104	-75
	46085ESJ	Carlet	46085	1,372,714	393	160	125	256	160	125
	46086ESJ	Carrícola	46086	-0.7169	203	169	-81	155	169	-81
	46087ESJ	Casas Altas	46087	-974,256	42	169	-70	41	169	-70
	46088ESJ	Casas Bajas	46088	-1,466,823	7	169	-40	7	169	-40
	46089ESJ	Casinos	46089	24,021	299	113	10	168	113	10
	46090ESJ	Castelló de Rugat	46090	-144,032	156	52	-104	129	52	-104
	46091ESJ	Castellonet de la Conquesta	46091	-123,433	162	169	-89	133	169	-89

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	46092ESJ	Castielfabib	46092	-1,083,057	31	169	-22	31	169	-22
	46093ESJ	Catadau	46093	-172,928	150	118	11	124	118	11
	46094ESJ	Catarroja	46094	1,449,334	397	193	174	260	193	174
	46095ESJ	Caudete de las Fuentes	46095	-717,402	68	20	-164	67	20	-164
	46096ESJ	Cerdà	46096	-1,032,271	36	22	-216	35	22	-216
	46097ESJ	Cofrentes	46097	-99,040	173	40	-65	140	40	-65
	46098ESJ	Corbera	46098	-209,149	139	91	-58	119	91	-58
	46099ESJ	Cortes de Pallás	46099	-746,422	61	169	3	60	169	3
	46100ESJ	Cotes	46100	-1,232,669	15	169	-83	15	169	-83
	46101ESJ	Quart de les Valls	46101	-580,637	82	59	-112	80	59	-112
	46102ESJ	Quart de Poblet	46102	1,056,752	382	188	173	245	188	173
	46103ESJ	Quartell	46103	-207,912	140	49	-129	120	49	-129
	46104ESJ	Quatretonda	46104	269,106	325	80	12	190	80	12
	46105ESJ	Cullera	46105	899,841	369	195	182	232	195	182
	46106ESJ	Chelva	46106	439,655	343	66	14	206	66	14
	46107ESJ	Chella	46107	-65,251	185	100	-20	146	100	-20
	46108ESJ	Chera	46108	-839,912	51	169	-4	50	169	-4
	46109ESJ	Cheste	46109	349,276	334	164	124	198	164	124
	46110ESJ	Xirivella	46110	1,148,242	387	182	152	250	182	152
	46111ESJ	Chiva	46111	769,530	359	175	142	222	175	142
	46112ESJ	Chulilla	46112	-335,858	122	169	32	111	169	32
	46113ESJ	Daimús	46113	237,572	321	99	-27	186	99	-27
	46114ESJ	Domeño	46114	-40,166	191	1	-224	149	1	-224

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	46115ESJ	Dos Aguas	46115	-1,491,227	6	169	-52	6	169	-52
	46116ESJ	Eliana (l?)	46116	1,266,873	390	170	127	253	170	127
	46117ESJ	Emperador	46117	-961,538	45	44	-209	44	44	-209
	46118ESJ	Enguera	46118	322,685	329	146	69	193	146	69
	46119ESJ	Ènova (l?)	46119	-796,295	56	29	-172	55	29	-172
	46120ESJ	Estivella	46120	-87,185	178	56	-84	144	56	-84
	46121ESJ	Estubeny	46121	-198,442	143	169	-64	121	169	-64
	46122ESJ	Faura	46122	-161,423	153	92	-63	126	92	-63
	46123ESJ	Favara	46123	-381,341	112	141	47	105	141	47
	46124ESJ	Fontanars dels Alforins	46124	-547,698	88	17	-171	86	17	-171
	46125ESJ	Fortaleny	46125	-550,225	87	16	-198	85	16	-198
	46126ESJ	Foios	46126	441,707	344	165	103	207	165	103
	46127ESJ	Font d?En Carròs (la)	46127	205,758	320	101	15	185	101	15
	46128ESJ	Font de la Figuera (la)	46128	0.6100	294	41	-49	165	41	-49
	46129ESJ	Fuenterrobles	46129	-1,077,813	32	38	-119	32	38	-119
	46130ESJ	Gavarda	46130	-654,154	73	24	-172	72	24	-172
	46131ESJ	Gandia	46131	1,681,421	401	219	217	264	208	206
	46132ESJ	Genovés	46132	-480,153	100	78	-18	95	78	-18
	46133ESJ	Gestalgar	46133	-1,355,279	10	169	-43	10	169	-43
	46134ESJ	Gilet	46134	-114,971	166	145	6	136	145	6
	46135ESJ	Godella	46135	1,112,321	385	194	143	248	194	143
	46136ESJ	Godelleta	46136	-29,046	195	87	-32	152	87	-32

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	46137ESJ	Granja de la Costera (la)	46137	-1,277,033	13	169	-78	13	169	-78
	46138ESJ	Guadasequies	46138	-179,615	147	169	-61	123	169	-61
	46139ESJ	Guadassuar	46139	390,762	336	125	9	199	125	9
	46140ESJ	Guardamar de la Safor	46140	-970,112	44	169	-82	43	169	-82
	46141ESJ	Higueruelas	46141	-632,348	76	169	-57	75	169	-57
	46142ESJ	Jalance	46142	-852,522	49	11	-148	48	11	-148
	46143ESJ	Xeraco	46143	178,309	319	132	34	184	132	34
	46144ESJ	Jarafuel	46144	-971,355	43	169	-29	42	169	-29
	46145ESJ	Xàtiva	46145	1,139,810	386	203	193	249	203	193
	46146ESJ	Xeresa	46146	-280,695	127	106	-44	113	106	-44
	46147ESJ	Llíria	46147	1,279,435	391	186	169	254	186	169
	46148ESJ	Loriguilla	46148	-68,708	183	51	-116	145	51	-116
	46149ESJ	Losa del Obispo	46149	-524,493	92	169	6	88	169	6
	46150ESJ	Llutxent	46150	-130,791	160	96	-32	132	96	-32
	46151ESJ	Llocnou d?En Fenollet	46151	-736,442	64	12	-216	63	12	-216
	46152ESJ	Lugar Nuevo de la Corona	46152	-156,035	154	169	-86	127	169	-86
	46153ESJ	Llocnou de Sant Jeroni	46153	-883,165	47	10	-234	46	10	-234
	46154ESJ	Llanera de Ranes	46154	144,339	315	32	-68	182	32	-68
	46155ESJ	Llaurí	46155	-743,813	62	58	-125	61	58	-125
	46156ESJ	Llombai	46156	-564,601	84	73	-9	82	73	-9
	46157ESJ	Llosa de Ranes (la)	46157	33,745	301	79	-14	170	79	-14
	46158ESJ	Macastre	46158	-1,197,419	18	43	-157	18	43	-157
	46159ESJ	Manises	46159	1,087,408	383	177	148	246	177	148

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	46160ESJ	Manuel	46160	49,871	306	107	16	175	107	16
	46161ESJ	Marines	46161	75,201	309	13	-98	178	13	-98
	46162ESJ	Masalavés	46162	14,183	298	77	-33	167	77	-33
	46163ESJ	Massalfassar	46163	-223,960	138	123	-18	118	123	-18
	46164ESJ	Massamagrell	46164	281,581	327	162	91	191	162	91
	46165ESJ	Massanassa	46165	670,164	353	161	112	216	161	112
	46166ESJ	Meliana	46166	913,853	370	159	101	233	159	101
	46167ESJ	Millares	46167	-758,096	60	169	-38	59	169	-38
	46168ESJ	Miramar	46168	-1,031,089	37	127	-34	36	127	-34
	46169ESJ	Mislata	46169	1,314,027	392	207	201	255	205	199
	46170ESJ	Mogente/Moixent	46170	52,476	307	116	46	176	116	46
	46171ESJ	Moncada	46171	1,228,158	388	173	145	251	173	145
	46172ESJ	Monserrat	46172	259,705	324	124	76	189	124	76
	46173ESJ	Montaverner	46173	-349,098	118	26	-169	110	26	-169
	46174ESJ	Montesa	46174	-266,129	130	48	-99	116	48	-99
	46175ESJ	Montichelvo	46175	-667,008	72	18	-209	71	18	-209
	46176ESJ	Montroy	46176	-120,972	164	81	-41	134	81	-41
	46177ESJ	Museros	46177	328,883	332	137	49	196	137	49
	46178ESJ	Náquera	46178	-0.0778	208	167	72	158	167	72
	46179ESJ	Navarrés	46179	98,976	310	95	-9	179	95	-9
	46180ESJ	Novelé/Novetlè	46180	-1,088,403	29	21	-225	29	21	-225
	46181ESJ	Oliva	46181	799,482	360	199	185	223	199	185
	46182ESJ	Olocau	46182	-737,781	63	138	-16	62	138	-16

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	46183ESJ	Olleria (l?)	46183	712,214	356	128	73	219	128	73
	46184ESJ	Ontinyent	46184	1,441,135	396	197	189	259	197	189
	46185ESJ	Otos	46185	-1,141,563	25	15	-207	25	15	-207
	46186ESJ	Paiporta	46186	947,039	372	179	132	235	179	132
	46187ESJ	Palma de Gandía	46187	-632,286	77	98	-23	76	98	-23
	46188ESJ	Palmera	46188	-397,369	110	46	-170	103	46	-170
	46189ESJ	Palomar (el)	46189	-1,538,266	5	7	-203	5	7	-203
	46190ESJ	Paterna	46190	2,290,690	402	247	242	265	209	204
	46191ESJ	Pedralba	46191	63,243	308	126	63	177	126	63
	46192ESJ	Petrés	46192	-682,098	69	25	-160	68	25	-160
	46193ESJ	Picanya	46193	555,460	350	184	143	213	184	143
	46194ESJ	Picassent	46194	752,093	357	189	157	220	189	157
	46195ESJ	Piles	46195	0.0624	279	60	-93	161	60	-93
	46196ESJ	Pinet	46196	-1,381,241	8	169	-66	8	169	-66
	46197ESJ	Polinyà de Xúquer	46197	-87,347	177	68	-62	143	68	-62
	46198ESJ	Potríes	46198	-1,130,806	26	39	-178	26	39	-178
	46199ESJ	Pobla de Farnals (la)	46199	0.5670	293	130	29	164	130	29
	46200ESJ	Pobla del Duc (la)	46200	-560,822	85	114	-4	83	114	-4
	46201ESJ	Puebla de San Miguel	46201	-559,141	86	169	-68	84	169	-68
	46202ESJ	Pobla de Vallbona (la)	46202	697,477	355	201	165	218	201	165
	46203ESJ	Pobla Llarga (la)	46203	-64,934	186	129	15	147	129	15
	46204ESJ	Puig	46204	610,586	351	153	99	214	153	99

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	46205ESJ	Puçol	46205	1,677,738	400	156	131	263	156	131
	46206ESJ	Quesa	46206	-352,525	117	169	57	109	169	57
	46207ESJ	Rafelbuñol/Rafelbunyol	46207	508,080	346	152	78	209	152	78
	46208ESJ	Rafelcofer	46208	-446,471	106	61	-132	99	61	-132
	46209ESJ	Rafelguaraf	46209	-58,625	187	83	-69	148	83	-69
	46210ESJ	Ráfol de Salem	46210	-880,163	48	6	-228	47	6	-228
	46211ESJ	Real de Gandía	46211	-414,685	109	143	-2	102	143	-2
	46212ESJ	Real de Montroi	46212	-437,115	107	67	-95	100	67	-95
	46213ESJ	Requena	46213	895,039	367	183	174	230	183	174
	46214ESJ	Riba-roja de Túria	46214	947,206	373	196	180	236	196	180
	46215ESJ	Riola	46215	-646,447	74	55	-113	73	55	-113
	46216ESJ	Rocafort	46216	998,418	378	171	90	241	171	90
	46217ESJ	Rotglà i Corberà	46217	-266,819	129	34	-112	115	34	-112
	46218ESJ	Rótova	46218	-389,936	111	30	-193	104	30	-193
	46219ESJ	Rugat	46219	-1,872,149	3	169	-92	3	169	-92
	46220ESJ	Sagunto/Sagunt	46220	1,374,968	394	210	206	257	207	203
	46221ESJ	Salem	46221	-1,219,870	16	3	-229	16	3	-229
	46222ESJ	San Juan de Énova	46222	-1,158,071	24	8	-237	24	8	-237
	46223ESJ	Sedaví	46223	760,815	358	134	47	221	134	47
	46224ESJ	Segart	46224	-26,724	197	169	-49	153	169	-49
	46225ESJ	Sellent	46225	-414,895	108	2	-197	101	2	-197
	46227ESJ	Senyera	46227	-547,399	89	42	-169	87	42	-169
	46228ESJ	Serra	46228	-98,285	174	122	-5	141	122	-5

Escala	ID	Nombre	Ent. Sup	Riesgo (val)	Ranking Absoluto Riesgo	Ranking Absoluto Estado	Ranking Absoluto Evol Est.	Ranking Relativo Riesgo	Ranking Relativo Estado	Ranking Relativo Evol Est.
	46229ESJ	Siete Aguas	46229	-812,591	54	115	13	53	115	13
	46230ESJ	Silla	46230	963,643	374	176	149	237	176	149
	46231ESJ	Simat de la Valldigna	46231	160,144	317	105	-20	183	105	-20
	46232ESJ	Sinarcas	46232	-511,643	95	23	-120	90	23	-120
	46233ESJ	Sollana	46233	0.2357	287	93	4	162	93	4
	46234ESJ	Sot de Chera	46234	-726,864	66	169	-7	65	169	-7
	46235ESJ	Sueca	46235	1,021,328	380	198	186	243	198	186
	46236ESJ	Sumacàrcer	46236	-272,343	128	50	-127	114	50	-127
	46237ESJ	Tavernes Blanques	46237	416,673	340	158	93	203	158	93
	46238ESJ	Tavernes de la Valldigna	46238	934,383	371	178	141	234	178	141
	46239ESJ	Teresa de Cofrentes	46239	-721,051	67	169	4	66	169	4
	46240ESJ	Terrateig	46240	-829,068	52	169	-72	51	169	-72
	46241ESJ	Titaguas	46241	-488,075	98	169	18	93	169	18
	46242ESJ	Torrebaja	46242	-483,432	99	169	-1	94	169	-1
	46243ESJ	Torrella	46243	-827,765	53	169	-90	52	169	-90
	46244ESJ	Torrent	46244	1,575,991	399	208	205	262	206	203
	46245ESJ	Torres Torres	46245	-1,003,521	40	88	-115	39	88	-115
	46246ESJ	Tous	46246	-1,095,483	28	31	-177	28	31	-177
	46247ESJ	Tuéjar	46247	-477,966	102	45	-38	96	45	-38
	46248ESJ	Turís	46248	243,051	322	163	106	187	163	106
	46249ESJ	Utiel	46249	-0.0503	210	190	172	159	190	172
	46250ESJ	Valencia	46250	2,714,889	403	335	334	266	214	213
	46251ESJ	Vallada	46251	117,957	312	97	12	181	97	12

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	46252ESJ	Vallanca	46252	1.48E-03	222	169	-88	160	169	-88
	46253ESJ	Vallés	46253	-333,611	123	169	-93	112	169	-93
	46254ESJ	Venta del Moro	46254	-675,078	71	64	-65	70	64	-65
	46255ESJ	Villalonga	46255	-117,331	165	112	34	135	112	34
	46256ESJ	Vilamarxant	46256	332,515	333	149	85	197	149	85
	46257ESJ	Villanueva de Castellón	46257	436,328	342	136	70	205	136	70
	46258ESJ	Villar del Arzobispo	46258	32,611	300	135	59	169	135	59
	46259ESJ	Villargordo del Cabriel	46259	-803,719	55	169	34	54	169	34
	46260ESJ	Vinalesa	46260	-189,009	145	103	-21	122	103	-21
	46261ESJ	Yátova	46261	39,554	302	57	-23	171	57	-23
	46262ESJ	Yesa (La)	46262	-1,271,166	14	169	-44	14	169	-44
	46263ESJ	Zarra	46263	-2,215,212	1	169	-23	1	169	-23
	ESA11004	Algeciras	11004	150,779	316	286	233	8	4	3
	ESA11012	Cádiz	11012	1.63E-49	217	312	259	4	7	6
	ESA11015	Chiclana de la Frontera	11015	-236,050	137	285	232	1	3	2
	ESA11020	Jerez de la Frontera	11020	0.0181	271	327	274	7	8	7
	ESA11022	Línea de la Concepción	11022	8.84E+00	238	221	168	6	1	0
	ESA11027	Puerto de Santa María	11027	-205,381	141	301	248	2	6	5
	ESA11031	San Fernando	11031	1.50E+00	225	294	241	5	5	4
	ESA11032	Sanlúcar de Barrameda	11032	-50,640	189	235	182	3	2	1
	ESA14021	Córdoba	14021	0.0487	277	340	287	1	1	0
	ESA18087	Granada	18087	0.0060	261	338	285	2	2	1
	ESA18140	Motril	18140	-246,202	136	242	189	1	1	0

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	ESA21041	Huelva	21041	5.75E+00	234	313	260	1	1	0
	ESA23050	Jaén	23050	1.86E+00	227	299	246	2	2	1
	ESA23055	Linares	23055	-171,905	151	231	178	1	1	0
	ESA29025	Benalmádena	29025	-24,629	198	225	172	6	2	1
	ESA29051	Estepona	29051	-253,994	134	252	199	3	3	2
	ESA29054	Fuengirola	29054	-286,712	126	216	163	2	1	0
	ESA29067	Málaga	29067	0.0661	280	339	286	8	8	7
	ESA29069	Marbella	29069	-0.1962	206	280	227	7	7	6
	ESA29070	Mijas	29070	-594,160	80	269	216	1	6	5
	ESA29094	Vélez-Málaga	29094	-67,523	184	263	210	5	5	4
	ESA29901	Torremolinos	29901	-141,029	158	262	209	4	4	3
	ESA4013	Almería	4013	0.0352	274	333	280	3	3	2
	ESA4079	Roquetas de Mar	4079	-451,693	103	279	226	1	2	1
	ESA41004	Alcalá de Guadaíra	41004	-196,885	144	257	204	1	1	0
	ESA41038	Dos Hermanas	41038	-173,672	149	303	250	2	2	1
	ESA41091	Sevilla	41091	0.0172	270	345	292	3	3	2
	ESA4902	Ejido	4902	-4.74E+00	212	244	191	2	1	0
	ESB22125	Huesca	22125	0.0040	254	233	180	1	1	0
	ESB44216	Teruel	44216	-105,089	169	213	160	1	1	0
	ESB50297	Zaragoza	50297	0.4111	290	343	290	1	1	0
	ESC33004	Avilés	33004	-74,378	180	261	208	3	2	1
	ESC33024	Gijón	33024	0.0568	278	311	258	5	3	2
	ESC33031	Langreo	33031	-111,072	168	169	116	1	1	0
	ESC33037	MIERES DEL CAMINO	33037	-88,519	176	169	116	2	1	0
	ESC33044	Oviedo	33044	0.0155	267	334	281	4	4	3

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	ESD38006	Arona	38006	-18,465	201	276	223	2	1	0
	ESD38023	San Cristóbal de la Laguna	38023	-69,991	182	321	268	1	2	1
	ESD38038	Santa Cruz de Tenerife	38038	0.0870	282	331	278	3	3	2
	ESD7040	Palma de Mallorca	7040	0.2060	286	337	284	1	1	0
	ESE35004	Arrecife	35004	-1.19E-20	214	224	171	3	1	0
	ESE35016	Palmas de Gran Canaria	35016	132,584	314	341	288	4	4	3
	ESE35022	Santa Lucía de Tirajana	35022	-8.73E+00	211	241	188	2	2	1
	ESE35026	Telde	35026	-264,411	131	289	236	1	3	2
	ESEF39075	Santander	39075	0.0020	244	319	266	2	2	1
	ESEF39087	Torrelavega	39087	-478,368	101	251	198	1	1	0
	ESG24089	León	24089	-28,090	196	306	253	1	2	1
	ESG24115	Ponferrada	24115	-19,597	200	234	181	2	1	0
	ESG34120	Palencia	34120	-263,944	132	249	196	1	1	0
	ESG37274	Salamanca	37274	-31,937	193	292	239	1	1	0
	ESG40194	Segovia	40194	0.0020	245	238	185	1	1	0
	ESG42173	Soria	42173	-75,790	179	223	170	1	1	0
	ESG47186	Valladolid	47186	0.0037	251	329	276	1	1	0
	ESG49275	Zamora	49275	-373,387	114	268	215	1	1	0
	ESG5019	Ávila	5019	0.0021	246	245	192	1	1	0
	ESG9059	Burgos	9059	0.0021	247	297	244	1	1	0
	ESH13034	Ciudad Real	13034	3.62E-12	219	264	211	2	2	1
	ESH13071	Puertollano	13071	-21,388	199	229	176	1	1	0
	ESH16078	Cuenca	16078	0.0038	253	275	222	1	1	0
	ESH19130	Guadalajara	19130	4.18E+00	232	253	200	1	1	0
	ESH2003	Albacete	2003	0.1830	284	317	264	1	1	0

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	ESH45165	Talavera de la Reina	45165	0.0016	242	228	175	1	1	0
	ESH45168	Toledo	45168	0.1446	283	277	224	2	2	1
	ESI17079	Girona	17079	354,919	335	305	252	1	1	0
	ESI25120	Lleida	25120	0.1882	285	302	249	1	1	0
	ESI43123	Reus	43123	0.0160	269	248	195	2	1	0
	ESI43148	Tarragona	43148	3.34E-84	216	314	261	1	2	1
	ESI8015	Badalona	8015	0.0071	262	304	251	13	13	12
	ESI8019	Barcelona	8019	14,125	297	346	293	18	18	17
	ESI8056	Castelldefels	8056	-180,843	146	287	234	2	12	11
	ESI8073	Cornellà de Llobregat	8073	0.0021	249	232	179	8	6	5
	ESI8096	Granollers	8096	-2.66E-15	213	237	184	5	7	6
	ESI8101	Hospitalet de Llobregat	8101	0.0315	273	310	257	16	15	14
	ESI8113	Manresa	8113	0.0041	255	278	225	11	11	10
	ESI8121	Mataró	8121	0.0048	257	274	221	12	10	9
	ESI8124	Mollet del Vallès	8124	2.79E+00	229	206	153	6	1	0
	ESI8169	Prat de Llobregat	8169	-70,067	181	212	159	4	2	1
	ESI8184	Rubí	8184	-259,335	133	246	193	1	8	7
	ESI8187	Sabadell	8187	0.0078	263	316	263	14	16	15
	ESI8200	Sant Boi de Llobregat	8200	4.32E+00	233	226	173	7	4	3
	ESI8205	Sant Cugat del Vallès	8205	0.0706	281	308	255	17	14	13
	ESI8245	Santa Coloma de Gramenet	8245	0.0037	252	217	164	10	3	2
	ESI8279	Terrassa	8279	0.0022	250	328	275	9	17	16
	ESI8301	Viladecans	8301	-121,944	163	230	177	3	5	4
	ESI8307	Vilanova i la Geltrú	8307	0.0127	266	250	197	15	9	8
	ESJ12040	Castellón de la Plana	12040	0.0109	265	318	265	1	1	0
	ESJ3009	Alcoy	3009	-203,987	142	256	203	2	3	2
	ESJ3014	Alicante	3014	0.4394	291	336	283	6	7	6
	ESJ3031	Benidorm	3031	-0.5552	204	227	174	4	2	1
	ESJ3065	Elche	3065	281,327	326	315	262	7	6	5
	ESJ3066	Elda	3066	-41,616	190	209	156	3	1	0
	ESJ3099	Orihuela	3099	-288,581	125	283	230	1	4	3
	ESJ3133	Torrevieja	3133	-0.0755	209	298	245	5	5	4

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	ESJ46131	Gandía	46131	-114,869	167	281	228	137	213	160
	ESJ46190	Paterna	46190	-249,144	135	255	202	117	210	157
	ESJ46220	Sagunto	46220	-491,988	97	270	217	92	212	159
	ESJ46244	Torrent	46244	-143,692	157	266	213	130	211	158
	ESJ46250	Valencia	46250	823,010	363	344	291	226	215	162
	ESK10037	Cáceres	10037	0.3774	289	293	240	1	1	0
	ESK6015	Badajoz	6015	4.75E-15	218	323	270	1	2	1
	ESK6083	Mérida	6083	172,131	318	236	183	2	1	0
	ESL15030	Coruña	15030	0.0016	240	325	272	2	3	2
	ESL15036	Ferrol	15036	0.0017	243	273	220	3	1	0
	ESL15078	Santiago	15078	0.0050	258	320	267	4	2	1
	ESL15780	Santiago de Compostela	15078	7.65E+00	236	320	267	1	2	1
	ESL27028	Lugo	27028	0.0436	276	295	242	1	1	0
	ESL32054	Ourense	32054	118,471	313	300	247	1	1	0
	ESL36038	Pontevedra	36038	8.93E+00	239	291	238	1	1	0
	ESL36057	Vigo	36057	0.0052	259	332	279	2	2	1
	ESM 28005	Alcalá de Henares	28005	9.43E-01	224	288	235	13	15	14
	ESM 28006	Alcobendas	28006	-531,682	90	271	218	2	13	12
	ESM 28007	Alcorcón	28007	-99,072	172	258	205	11	10	9
	ESM 28047	Collado Villalba	28047	-348,227	119	265	212	5	11	10
	ESM 28049	Coslada	28049	-344,503	120	205	152	6	1	0
	ESM 28058	Fuenlabrada	28058	-53,481	188	214	161	12	3	2
	ESM 28065	Getafe	28065	-129,457	161	267	214	10	12	11
	ESM 28074	Leganés	28074	-298,688	124	240	187	8	7	6
	ESM 28079	Madrid	28079	10,407	296	347	294	17	17	16

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	ESM 28080	Majadahonda	28080	-1,071,593	33	243	190	1	8	7
	ESM 28092	Móstoles	28092	-175,235	148	239	186	9	6	5
	ESM 28106	Parla	28106	-339,501	121	218	165	7	4	3
	ESM 28115	Pozuelo de Alarcón	28115	2.73E+00	228	282	229	14	14	13
	ESM 28123	Rivas-Vaciamadrid	28123	-528,665	91	220	167	3	5	4
	ESM 28127	Rozas de Madrid (Las)	28127	0.0054	260	324	271	16	16	15
	ESM 28134	San Sebastián de los Reyes	28134	-512,614	94	254	201	4	9	8
	ESM 28148	Torrejón de Ardoz	28148	2.96E+00	231	211	158	15	2	1
	ESN30016	Cartagena	30016	0.2546	288	326	273	4	3	2
	ESN30024	Lorca	30024	0.0360	275	272	219	3	2	1
	ESN30027	Molina de Segura	30027	1.59E+00	226	260	207	1	1	0
	ESN30030	Murcia	30030	0.0156	268	342	289	2	4	3
	ESO31201	Pamplona	31201	1.03E-05	220	307	254	1	1	0
	ESP 1059	Vitoria-Gasteiz	1059	7.70E+00	237	309	256	1	1	0
	ESP20045	Irún	20045	0.0021	248	215	162	1	1	0
	ESP20069	San Sebastián	20069	0.0102	264	322	269	2	2	1
	ESP48013	Barakaldo	48013	2.80E+00	230	222	169	3	2	1
	ESP48020	Bilbao	48020	0.0042	256	330	277	4	4	3
	ESP48044	Getxo	48044	1.24E-01	223	259	206	2	3	2
	ESP48078	Portugalete	48078	0.0192	272	169	116	5	1	0
	ESP48082	Santurci	48082	-2.57E-129	215	169	116	1	1	0
	ESQ26089	Logroño	26089	2.77E-04	221	290	237	1	1	0
	ESR51001	Ceuta	51001	5.88E+00	235	296	243	1	1	0

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	ESS52001	Melilla	52001	0.0016	241	284	231	1	1	0