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Integrating spatial planning and flood risk management: A new conceptual framework for the spatially integrated policy infrastructure

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ABSTRACT

Flooding is a widely occurring natural hazard that noticeably damages property, people, and the environment. In the context of climate change, the integration of spatial planning with flood-risk management has gained prominence as an approach to mitigating the risks of flooding. The absence of easy access to integrated and high-quality information, and the technologies and tools to use information are among the factors that impede this integration. Limited research has been conducted to develop a framework and to investigate the role of information and technologies in this integration. This study draws primarily on the European experiences and literature and identifies three dimensions of the integration of spatial planning with flood-risk management: territorial, policy, and institutional. To facilitate integration and in accord with these three dimensions, a Spatially Integrated Policy Infrastructure (SIPI) is conceptualised that encompasses data and information, decision support and analysis tools, and access tools and protocols. This study presents the connections between SIPI elements and integration dimensions, which is important for a better understanding of roles of geographic information and technologies in integration. The conceptual framework of SIPI will govern further development and evaluation of SIPI.

1. Introduction and problem description

Flooding is a common natural hazard that noticeably damages properties, human lives, and the environment. Flooding contributed to about 39.26% of worldwide natural disasters and caused USD 397.3 billion worth damage between 2000 and 2014 (EM-DAT, 2015). Flooding can be caused by excessive or concentrated precipitation, rapid or heavy snowmelt, storm surge, or embankment failure (White, 2010). In addition, other disaster events or circumstances may trigger flooding under specific conditions, such as earthquake-triggered landslides (Xu, Fan, Huang, & Westen, 2009) or tsunamis (Jankaew et al., 2008). When they consider climate change, scientists predict an intensified global water circulation with respect to magnitude and frequency of extreme precipitation events (Dankers & Feyen, 2008), which would manifest as a global increase in the frequency and severity of floods and drought (Hirabayashi, Kanae, Emori, Oki, & Kimoto, 2008) and increases in uncertainty regarding coastal flooding from rising sea levels (Nicholls, 2004).

At the same time that the risk of devastating floods grows, the demands for development continue and in some regions even increase. Population growth, particularly in urban areas, is increasing the likelihood of the overuse of land in flood-prone areas (Larsen, 2009). For example, in England, about 5.2 million properties, accounting for about one-sixth of all properties, are located in areas at risk of flooding (Department of Environment Food and Rural Affairs & Environmental Agency, 2011). Adamson and Cussen (2003) pointed out that, in Ireland, the growing population and continual development in flood-prone areas are likely to raise the flood risk. These two areas are typical of the growing pressure that continual development is exerting on spatial planning and flood-risk management.

Actions that address flood risk in areas under continual development include: (1) strengthening existing or constructing new protective structures, such as embankments (Neuvel & Van Den Brink, 2009); (2) increasing natural retention and storage capacities, such as the “Room for the River” projects in Netherlands (Butler & Pidgeon, 2011); (3) expanding insurance for flood damage and improving flood resilience (Dawson et al., 2011); and (4) upgrading forecasting, early warning, and preparedness systems (Al-Sabhan, Mulligan, & Blackburn, 2003; Pathak & Eastaff, 2014). These measures tend to be implemented in isolation from each other and occasionally encounter local opposition such as in the case of increasing natural retention and storage capacities in the Netherlands (Neuvel & Van Der Knaap, 2010). Integration of different measures and cooperation among various types of interventions are required to ensure their effectiveness (Veraart et al., 2010; Wilson, 2006). The term *integration* is defined as

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an act or process to combine, unite, bring together, or incorporate parts into a whole so that they work together (Hornby, 2010).

This study proposes that geographic information (GI) and geographic technologies (GT) can support such integration specifically of spatial planning and flood-risk management by capitalizing on their utility in various planning and management activities, including land-use administration (Shariff, Hamzah, Mahmud, Yusof, & Ali, 2011), coastal risk management (Jeanson, Dolique, & Anthony, 2014; Zanuttigh et al., 2014), cultural heritages (McKeague, Corns, & Shaw, 2012), and organizations (Dessers et al., 2012). Also, GI is a useful tool to assess flood risks and mapping (Porter & Demeritt, 2012), prepare for flood disasters (Chang, Tseng, & Chen, 2007), evaluate development scenarios (Macharis & Crompvoets, 2014), and combine urban flood management with urban planning (Price & Vojinovic, 2008). A testament to the utility of GT and shared databases is the creation of spatial information infrastructures in more than 100 countries (De Man, 2007; Masser, 2005) and their application across various disciplines, such as economics, demographics, geo-history, sociology, and e-governance (Sridharan, 2015; Van Manen, Scholten, & Van De Velde, 2009). Similarly, accessible, appropriate, and comprehensive GI and GT support vital communication, cooperation, and coordination necessary to the integration of spatial planning with flood-risk management (Roche, Sureau, & Caron, 2003; Roose & Kull, 2012).

The first objective of this study is to identify the requirements for integrating spatial planning with flood-risk management and to conceptualise and identify the dimensions of 'integration', primarily in the European, and particularly in the Irish, context and framework. Then, the study aims to develop, as its second objective, a conceptual framework of an infrastructure, termed Spatially Integrated Policy Infrastructure (SIPI), which allows for sharing GI and decision support and analysis tools between spatial planning and flood-risk management.

2. Flood-risk management and spatial planning

2.1. Flood mitigation measures in flood-prone areas

In the field of flood governance, the recognition of 'flood-risk management' is increasing and replacing traditional methods of 'flood defence', 'flood protection', or, more recently, 'flood management' (Butler & Pidgeon, 2011; Galloway, 2008; Sayers, Hall, & Meadowcroft, 2002). The flood-risk management approach emphasises the importance of controlling the hazard and lessening social vulnerability to its effects, whereas the traditional methods merely seek to control the hazard (Galloway, 2008). Flood-risk management, therefore, deals with the outcomes, which are the combinations of the probabilities of an event occurring and the impacts associated with that event. Sayers et al. (2002) defined risk-based flood management as a whole-system approach that assesses and compares the structural and non-structural ways to pursue the optimal ameliorating effects.

Structural measures to mitigate flood hazards often imply the construction and maintenance of levees, dams, mobile elements such as sand bags and mobile flood walls, removing obstacles from flood plains, restricting construction, and controlling the design of the physical spaces in flood-prone areas (Kryžanowski, Brilly, Rusjan, & Schnabl, 2014; Neuvel & Van Den Brink, 2009). The new flood-risk management approach adapts the principles supporting structural measures from diverting water away from our area to making room for water. Examples of the new structural measures are two programmes: Make Space for Water in the UK (Butler & Pidgeon, 2011) and Room for the River in the Netherlands (Neuvel & Van Den Brink, 2009).

Non-structural measures apply knowledge, practices, agreements, and/or policies to mitigate flood hazards. For example, Dawson et al. (2011) summarized the three non-structural measures of land-use (spatial) planning, insurance, and improvements to resistance to the effects of flooding. Neuvel and Van den Brink (2009) argued that spatial planning is a promising instrument to reduce flood impacts. In another example, Butler and Pidgeon (2011) proposed that a desirable approach is to deliver governmental flood mitigation objectives with non-coercive guidance of citizen and organizational conduct.

Another vein of research on non-structural measures recognizes Information and Communication Technologies (ICT) as tools that aid flood mitigation because they support the formulation of appropriate risk-mitigation approaches that combine structural with non-structural measures. For example, Decision Support Systems and Geographic Information Systems inform decision makers with reliable information, such as hazard forecasts. These systems are communication tools that involve an array of stakeholders as well as educational tools that raise public awareness (Price & Vojinovic, 2008).

Thus, flood-risk management strategies no longer primarily rely on structural measures and, instead, combine structural with non-structural measures. Evidence from practice suggests that a combined approach is the most effective way to combat flood risk because it takes advantage of the individual strengths of the two approaches (Hall, Sayers, Walkden, & Panzeri, 2006; Hayes, 2004). The advantage of structural measures is that they aim to provide a physical protection to flood-prone areas, although their weaknesses are significant economic and environmental costs (Hall et al., 2006) and occasional failures due to inadequate planning and construction (Sills, Vroman, Wahl, & Schwanz, 2008). However, non-structural measures are economically efficient and environmentally friendly, but their effectiveness is sensitive to socioeconomic context and governmental behaviours (Dawson et al., 2011).

2.2. Spatial planning: potential for flood-risk management

Planning is a rational and systematic process of guiding public and private actions and influencing the future by identifying and analysing alternatives and outcomes (Davidoff & Reiner, 1962; Steiner, Butler, & American Planning Association, 2012). Spatial planning is a type of planning concerned with arranging physical space and guiding future activities within it according to suitability and other accepted principles (Kidd, 2007; Larsson, 2006). Planners work on the spatial distribution of types of land use, such as transportation, residential, institutional, commercial, and industrial. Thus, spatial planning is usually referred to as land-use planning or urban/regional planning (Davidoff & Reiner, 1962).

In flood-prone areas, spatial planning is expected to contribute to flood mitigation (Howe & White, 2004; White & Richards, 2007) mainly because it can influence the incidence of flooding and its consequential damage by regulating the locations of activities, types of land use, scales of development, and designs of physical structures (Neuvel & Van Der Knaap, 2010; White & Richards, 2007). For example, the approach applied in Germany and the 'Making Room for the River' approach in the Netherlands emphasises regulating land use to prevent the incidence of flooding by preventing incursions on water-retaining areas of the flood plain (Krieger, 2013; Van Heezik, 2008). Conversely, the 'Making Space for Water' project in England emphasises the consequences side of the risk equation and the impossibility of complete flood prevention. The French spatial planning system is similar to the British model in its goals (i.e., exposure reduction rather than probability prevention), but it is relatively less effective (Beucher, 2009; Pottier, Penning-Rowsell, Tunstall, & Hubert, 2005).

Furthermore, other characteristics distinguish spatial planning in flood-risk management. For example, spatial planning can influence crucial factors at multiple spatial scales, from local-level plans to national or even international strategic plans (White & Richards, 2007; Wynn, 2005). Planning authorities are generally given more power than flood-risk agencies regarding land-use planning and development control in the flood-prone areas (White & Richards, 2007).

Although the potential of spatial planning in flood mitigation is recognised, several practical obstacles impede its integration into mitigation plans. In the UK context, Howe and White (2004) found that the value added to flood-risk management by spatial planning was limited by deficient integration between these two fields and insufficient coordination among spatial scales. A further study, carried out by Wynn (2005), suggested that the great pressure for development in the UK has impeded the effectiveness of development control in flood-prone areas. White and Richards (2007) claimed that the UK is a long way from translating central guidelines into local planning practices with respect to flood mitigation. In the Netherlands, Neuvel and Van Den Brink (2009) pointed out that spatial planning is rarely considered as a flood mitigation measure and that flood mitigation measures, particularly those addressing adaptation to and recovery from flood hazards, are usually not well implemented into planning practices.

Therefore, the relationship between planning systems and flood-risk management is weak and should be strengthened and better coordinated. Involving more stakeholders with interests in flood mitigation might improve the quality and implementation of existing plans (Baker, Hincks, & Sherriff, 2010; Veraart et al., 2010). This could be an initial step towards an approach to flood mitigation that integrates spatial planning with flood-risk management.

3. Integration of spatial planning with flood-risk management

3.1. Integration dimensions

In practice, integration often refers to an approach to strengthen linkages between places, cooperation between sectors, or interconnections among policies (Kidd, 2007). Integration is often suggested as an approach to solve the most challenging contemporary issues that cannot be addressed by a single jurisdiction or from one perspective. For example, researchers have suggested the integrated approach to achieve disaster mitigation (Djalante, Holley, Thomalla, & Carnegie, 2013; Sutanta, Rajabifard, & Bishop, 2010), to promote sustainable development (Olazabal et al., 2010; Serageldin & Steer, 1994), to address environmental issues (Stead, 2008; Weber & Driessen, 2010), and to adapt to climate change (Van Oosterzee, Dale, & Preece, 2013).

This study first examines the connotation of the term *integration* from several perspectives, including general spatial planning, marine policy, spatial planning for health, and spatially-enabled governance for the reduction of disaster risks (Table 1). From the perspective of spatial planning for health, Kidd (2007) maintained that integration has three dimensions: (1) territorial, (2) sectoral, and (3) organizational. Drawing on advancements in the field of spatial planning, Vigar (2009) highlighted that integration means interactions between or among dimensions. From the perspective of spatially-enabled governance, Sutanta et al. (2010) built a framework that highlights the value of data and a platform for integration. Other researchers have contributed to one-dimensional conceptualizations of integration, such as territorial (Doucet, 2006), policy (Stead & Meijers, 2009), and actors (Burby, 2003; Stead, 2008).

Scholars sometimes use different terms to denote the same dimension of integration. Moreover, the conceptual boundaries between dimensions are not strictly delineated. For example, Kidd's (2007) 'sectoral integration' means 'integration of different public policy domains' and 'integration of public, private, and voluntary sector activity within a territory' (p. 167). Thus, Kidd's (2007) 'sectoral integration' rests between the 'issue' dimension and the 'actor' dimension of Underdal's (1980) conceptualization. Therefore, Kidd's (2007) 'sectoral integration' may be understood as a combination of 'sectoral policy integration' and 'sectoral actors integration'.

The blurred boundaries between the dimensions of integration suggest that these dimensions are closely related. First, the territorial dimension is likely to influence the policy integration approach. Expecting the effect of the territorial dimension, Vigar (2009) adopted a methodology of 'governance lines' to analyse Scottish policies. The methodology allowed the investigator to spatially assess the linkages between the vertical policy process and the spatially horizontal policy. Second, policy integration cannot be achieved without efficient coordination among a variety of institutions and actors. As identified by Stead and Meijers (2009), institutional or organizational factors are important, but they could both inhibit and facilitate policy integration.

Although different integration frameworks may use different terms and structures because they rely on different disciplines and perspectives, this study generalises three prominent dimensions of integration: (1) territorial integration, (2) policy integration, and (3) institutional integration. The term *territorial integration* deals with reconciling inconsistencies of spatial jurisdictions. It encompasses vertical integration among spatial scales and horizontal integration across adjacent areas or areas with some extent of shared interest (Kidd, 2007). The term *policy integration* is the management of cross-cutting issues in policy making that transcend the boundaries of the established policy fields and do not correspond to the institutional responsibilities of individual organisations (Stead & Meijers, 2009). Policy integration aims to devise policies that are in accord with each other through an aggregated process of comprehensive input. In this aggregated process, all alternatives are compared in various perspectives and screened based on priorities that are based on mutual interests (Underdal, 1980). The term *institutional integration* indicates institutions that are built and managed to benefit communication, cooperation, and coordination between or among parties (Eggenberger & Partidário, 2000). Activities, such as the coordinated management of information, application of efficient telecommunication technologies, common-use sets of goals and principles, standardized business processes, and enhanced communication between institutions and their departments/representatives, support institutions' efforts to work together harmoniously and to

Table 1
The dimensions of integration in the current published research literature.

Literature	(Underdal (1980))	(Kidd (2007))	(Sutanta et al. (2010))	(Vigar (2009))	Other literature on one dimension
Dimensions of integration	Time				
			Data Platform		
	Space	Territorial integration		Interaction at spatial levels	Territorial Cohesion (Doucet (2006))
	Issues	Sectoral integration	Policy	Interaction between policies	Policy integration (Stead & Meijers (2009))
	Actors	Organizational integration	Organization	Interaction between actions/institutions	Citizen involvement (Burby (2003)) Institutional aspects (Stead (2008)) Organizational integration (Barki and Pinsonneault (2005))
Perspective	Marine policy integration	Integrated spatial planning related to health	Integrated spatial planning with disaster risk reduction regarding spatially-enabled government	From integrated spatial planning perspectives	

tightly coordinate their activities (Barki & Pinsonneault, 2005). Thus, these measures fit into the realm of institutional integration.

The dimensions of integration help us to understand the meaning of integration in general terms and from several perspectives. Section 3.2 interprets these dimensions in the case of spatial planning and flood-risk management by identifying specific issues in each dimension. However, because the dimensions are interrelated, the issues of one dimension are not and cannot be addressed in isolation from the issues of the other two dimensions.

3.2. The dimensions of integration of spatial planning with flood-risk management

Using the three dimensions generalised from the current research literature, we identified key issues that feature the practical aspects of integrating spatial planning (SP) with flood-risk management (FRM) (Table 2).

3.2.1. Territorial integration

Territorial integration focuses on consistency across boundaries (horizontal integration) and alignment among spatial scales (vertical integration). To address territorial issues, a hierarchical approach is often applied, as in, for example, Kolossov's (2005) study of border and boundary and in Baskent and Keles (2005) study on forest planning. A *hierarchy* can be defined as a set of elements, each of which rests at a different level. An element at a relatively lower level has only one superior or root element at the next higher level (Baskent & Keles, 2005; Dawkins, 1976). In a spatial context, the levels of a hierarchy are defined as spatial scales ranging from the local to the global (Healey, 2004). For example, in Rajabifard, Escobar, and Williamson's (2000) model, the hierarchy of Spatial Data Infrastructure comprised the global, regional, national, state/provincial, local, and corporate levels. The approach to integrating two systems within the same spatial hierarchical level demands the horizontal alignment of activities within the same jurisdictional level and the vertical alignment of activities at a lower spatial level with activities at a higher spatial level. However, when integrating systems that have different hierarchical structures, this approach is greatly challenged because of the multiplicity of relationships that cannot be reduced to simple horizontal and vertical relationships (De Man, 2007).

Table 2
The dimensions of the integration of spatial planning with flood-risk management.

Integration dimensions	Integration goals	Key issues to be addressed in the context of SP and FRM
Territorial	Vertical and horizontal integration	• Sharing and exchanging information among neighbouring jurisdictions and overlapping jurisdictions because the SP spatial hierarchy differs from that of FRM • Check the consistency and conflict among spatial policy levels
Policy	Comprehensive instruments	• Policies and strategies should be comprehensive and consider the consequences in a broad scope of issues • Comprehensive input from various actors, such as planning authorities, publics, NGOs, governments, private companies, FRM authorities, and researchers
	Rational policy making procedure	• Planning policy alternatives are evaluated from the perspective of flood-risk mitigation • Flood-risk management alternatives are evaluated from the perspective of planning and development
Institutional	Shared context	• Coordinated management of information • Operating standardized business process • Sharing common sets of goals and principles
	Communication	• Applying efficient telecommunication technologies • Building communication channels between institutions and their departments and representatives

The example of territorial integration of spatial planning with flood-risk management involves different hierarchical structures. Territorial integration in this case requires aligning the spatial mismatches of policies and of institutions. First, there is a spatial hierarchy mismatch between SP institutions and FRM institutions, as noted by several scholars (Howe & White, 2004; White & Richards, 2007). Specifically, the jurisdictions of planning authorities, which are often defined according to human activities, rarely correspond to the jurisdictions of flood-risk management authorities, which are often natural geographic districts. Second, the spatial hierarchy of SP policies does not match that of FRM policies. Fig. 1 illustrates the spatial mismatch in the policy and institutional hierarchies in the Irish context, but different countries may apply different structures.

This hierarchical mismatch results in a complex process of integration. For example, the Regional Planning Guidelines should be integrated with both the Catchment FRAM Plan (lower spatial scale) and the National CFRAM Programme (higher spatial scale) and the Catchment FRAM Plan should be integrated with Regional Planning Guidelines, Development Plan, and Local Area Plan.

3.2.2. Policy integration

Policy is used in this study as an abbreviation of *governmental policy*, which refers to an intervening and facilitating 'course of actions of governmental actors to provide intentional guidance to solve the collective issues' (Jiao & Boons, 2014, p. 14). However, Hall (1993) proposes that policy implies the instrumental settings (such as the minimum lending rates or annual budgets) and the hierarchy of goals behind policies as well as the instruments per se (the techniques applied to achieve policy goals).

In that context, policy integration implies that the policymaking process is a joint process as well as the policy's reflection of a combined and comprehensive consideration. Weber and Driessen's (2010) framework for integrating noise and spatial planning suggested that there are two types of factors: instruments and routine decision-making procedures. In another study, Jordan and Lenschow (2010) identified three instruments regarding complex and contingent policy integration: administrative means, implementation of rational structures and procedures, and the minds of the policy makers and other relevant stakeholders. Based on these sources, this study defines *policy integration* in terms of the design of comprehensive instruments and establishment of rational and joint policy-making procedures. Finally, efforts should be made to involve comprehensive stakeholders because more stakeholder involvement leads to stronger, more comprehensive decisions that are more likely to be implemented (Baker, Coaffee, & Sherriff, 2007; Burby, 2003). Barriers to that goal include limited time and a lack of resources, which may impede the involvement of stakeholders in planning and decision-making processes (Baker et al., 2010).

3.2.3. Institutional integration

Integration in this study primarily involves two types of institutions: those related to spatial planning and those related to flood-risk management. In this case, there are other stakeholders aside from the institutions of planning authority and flood authority that are or could be part of the process, but they are more involved in the policy integration process than institutional integration because they contribute to the comprehensiveness of policy input. From an operational perspective, integration is based on shared context, such as coordinated management of information and material flows (Barki & Pinsonneault, 2005) and on collective knowledge and mutually beneficial goals or interests (Oliver, 1990). When common understanding of the problem, the process, and each institution's role were missing, for example, stakeholders' and public engagement were impeded in the English planning system (Kitchen & Whitney, 2004). Furthermore, based on

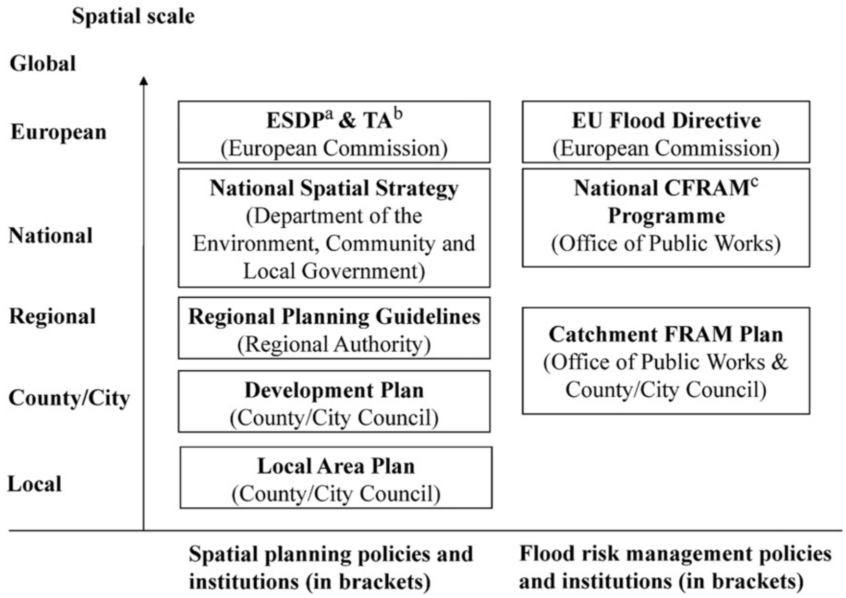

Fig. 1. Mismatch of spatial hierarchy in SP and FRM policies and institutions in Irish context. [a]ESDP = European Spatial Development Perspective. [b]TA = Territorial Agenda of the European Union 2020. [c]CFRAM = Catchment Flood-risk Assessment and Management.

shared context, integration requires tools, technologies and social connections to support uniform and smooth communication. However, as Evans-Cowley and Hollander (2010) pointed out, communication methods and technologies in use were limited in providing equal access.

4. Geographic information (GI) and geographic technologies (GT): a potential facilitator

The integration of spatial planning with flood-risk management in all of the relevant dimensions requires a variety of facilitators from the political, financial, organizational, management, and cultural sectors (Stead & Meijers, 2009). In this study, GI and GT are focused on as potential facilitators because they have proven to be valuable supports for spatial planning and flood-risk management. For example, GI-based planning support tools are used in numerous planning tasks (Pettit & Pullar, 2009), such as site selection (Chang, Parvathinathan, & Breeden, 2008; Van Haaren & Fthenakis, 2011), plan assessment (Oh & Jeong, 2007), management of urban activities (Barredo, Kasanko, McCormick, & Lavalle, 2003; Jat, Garg, & Khare, 2008), plan making (Oana, Harutyun, Brendan, & Sheila, 2011; Scholten & Stillwell, 1990), public participation (McCall & Dunn, 2012; Simão, Densham, & Haklay, 2009), and integration of planning with strategic environmental assessments (Vukicevic & Nedovic-Budic, 2012). In addition, GI and GT are used to predict flood extent (Pradhan, Shafiee, & Pirasteh, 2009; Werner, 2001), assess flood risks (Zhang et al., 2009), evaluate floodplain development (Nedovic-Budic, Kan, Johnston, Sparks, & White, 2006), and evaluate the effects of land-use changes on hydrological process (Bahremand et al., 2007).

Although the power and usefulness of GI and GT have been studied and proven since the 1990s, the absence of shared GI and GT assistance is still one of the factors impeding the integration of spatial planning with flood-risk management. Regarding this, Neuvel and Van Den Brink (2009) maintained that lack of information, such as risk maps, is a factor that impedes planning authorities' use of spatial plans to mitigate flood consequences. Acknowledging the limited availability of flood maps, the EU Floods Directive (2007/60/EC) requires that member states prepare flood hazard maps and flood-risk maps by 22 December 2013. Even where information exists, there are many other reasons why flood information is not shared in practice, such as lack of access to information or lack of legal requirements to use the information. According to De Moel, Van Alphen, and Aerts (2009), by 2009, 24 EU member states had flood extent maps of either their entire or a significant part of their territories. Despite these developments, only eight member states had binding legislation supporting the use of flood hazard or risk information in the spatial planning process. Additionally, poor understanding of the information decreases confidence in its use or leads to the misuse of shared information. For example, the accuracy of the spatial boundaries between flood hazardous and non-hazardous areas is often questioned. Misunderstanding these boundaries may result in absolute planning or development boundaries with a low level of awareness of flood risk in the 'safe areas', which is located outside of the hazardous areas but still with probability of being flooded (Neuvel & Van Den Brink, 2009).

This study proposes that sharing GI and GT could increase the quantity and quality of the exchange of information and knowledge between spatial planning and flood-risk management and, thus, facilitate their integration. As Schuurman (2003, p. 2) suggested, GI and GT are one 'integration medium' that can improve a mutual understanding of issues and promote discursive communication. Improving collaboration and communication is recognized as the most important benefit of GI and GT (Pelzer, Geertman, van der Heijden, & Rouwette, 2014). Moreover, Saleh et al. (2009) suggested that integrating comprehensive geographic and environmental data with management tools in simulation and decision tools is a promising approach to flood-risk reduction and strategic planning. The potential of GI and GT as an 'integration medium' is also recognized in a study by Smith, Wall, and Blackstock (2013) that describes GI and GT as boundary objects that are artefacts across different social worlds with different meanings in each. From this perspective, the authors claimed that GI and GT facilitate mutual understanding on the one hand whereas they represent the contest between different social values and power on the other hand. Thus, GI and GT are useful for establishing a comprehensive understanding of complex phenomena, although they should not replace the processes of discursive interaction (discussion and communication).

4.1. Examples of sharing GI and GT

Data-sharing activities are mostly driven by mutual goals, desires to save resources, and existing functional dependencies (Nedovic-Budic, Pinto, & Warnecke, 2011). Many established Geo-portals and Spatial

Table 3
Examples of Information Infrastructure projects related to spatial planning and flood issues (last accessed on 18 March, 2015).

II name	Area	Aims	Information	Link
Global Runoff Data Centre	Global	To provide data support for earth scientists to analyse global climate trends and assess environmental impacts/risks; facilitate data exchange	Watershed boundaries Archive river discharge data up to 200 years old	http://www.bafg.de/GRDC/EN/Home/homepage_node.html
Infrastructure for Spatial Information in the European Community (INSPIRE)	Europe	To enable sharing of environmental spatial data among public sector organisations and facilitate public access to spatial information in Europe	Three annex data themes Data on flood-risk zones is in Annex III: natural risk zones	http://inspire.jrc.ec.europa.eu/index.cfm/pageid/48
The European Floods Portal	Europe	To bring together information from active research regarding river floods and flood risk in Europe	Flood risk, ongoing floods, flood forecasts, climate change impacts	http://floods.jrc.ec.europa.eu/efas-flood-forecasts
European Environment Agency Water Data Centre	Europe	To provide the European entry point for water-related data as part of Water Information System for Europe (WISE)	Broad range of data on water, pollution, flood, biology, and so on, in various formats; e.g., text, tables, images, and maps	http://www.eea.europa.eu/themes/water/dc
Myplan Viewer	Ireland	To create a 'one-stop shop' for information on plans; provide information relevant to planning decision-making	Planning zones, censuses, heritage sites, patterns of housing development, and flood maps	http://www.myplan.ie/viewer/
Irish Water Maps	Ireland	To support River Basin Management Plans	Water body status, risks, objectives, and measures	http://watermaps.wfdireland.ie/NsShare_Web/Viewer.aspx?Site=NsShare&ReloadKey=True
Flood Hazard Mapping	Ireland	To provide information about locations of known flood events in Ireland	Point locations of historical flood events and reports, photos, and press articles about those floods	http://www.floodmaps.ie/
Sistema Informativo Territoriale	Italy	To provide useful basic information for a more adequate estimation of the hydraulic vulnerability and flood susceptibility (Morelli, Segoni, Manzo, Ermini, and Catani (2012))	Buildings, assets, bridges, hydraulic works, weirs, drainage outlets, dikes, river banks, structural damages, fluvial bars, and eroding banks	http://sitweb.provincia.fi.it/website/plantario/viewer.htm
Flood Insurance Rate Map (FIRM)	USA	To provide public information about residential or community projected risks of flood hazards	Preliminary Flood Insurance Rate Maps (FIRM), Flood Insurance Study reports, and FIRM database	http://hazards.fema.gov/femaportal/prelimdownload/
National Flood Risk Information Portal	Australia	To make flood-risk data accessible from a central location	Flood extent, water depth, and flood studies	http://www.ga.gov.au/flood-study-search/

Data Infrastructures (SDI) (Table 3) suggest that activities in which GI is shared among different parties are technologically achievable. However, to function as an integration medium, those infrastructures must provide precise and comprehensive information.

Comprehensiveness is weak in the examples of Global Runoff Data Centre, The European Floods Portal, EEA water data centre, and Irish Water Maps described in Table 3. These examples share accurate and reliable hydrography and flood information, but they omit information on land-use planning. Other projects share comprehensive information, but they do not focus on spatial planning and flood-risk management. For example, the European Union (EU) spatial data infrastructure directive, Infrastructure for Spatial Information in the European Community (INSPIRE), requires collection and sharing of a wide range of data on 34 themes, such as hydrography, transportation, land use, environmental monitoring facilities, and natural risk zones. It promotes the sharing of comprehensive information, but it does not highlight the integration of spatial planning with flood-risk management.

Examples of sharing information on both flood and spatial planning are rare. A study by Morelli et al. (2012) is an example that delivers a GIS database on an Arno river (Italy) case study. This database is built to visualize the spatial distributions of natural and manmade elements. The authors suggested that the geo-database could serve as a practical tool to manage hydrological risks, hydraulic policies, and urban planning. Another example is the Irish Myplan Viewer that provides a one-stop shop of comprehensive information for planning and flood maps. These two examples of spatial data infrastructures benefit the integration of spatial planning with flood-risk management to some extent.

However, limiting sharing to information may limit the extent of integration. Sharing models and systems that are used for planning and flood-risk management would enhance the integration medium role of GI and GT. By doing so, judgments and analyses behind the models are exchanged, as well as planning support systems and decision support systems (Boerboom, 2013). To that end, Küpferle, Kräßig, and Hirschhäuser (2009) integrated flood models into a land-use planning system. In addition, efforts to achieve this extent of sharing are found among the European Community Initiative INTERREG III programmes. The main objective of the INTERREG III programmes is to realize a more cohesive, balanced, and sustainable territorial development and improved territorial integration in the European Community (INTERREG IIIB NWE).

The INTERREG III includes a project referred to as 'nofdp' (i.e., nature-oriented flood damage prevention) that delivers an open-source interactive planning and communications software tool, the Information and Decision Support System (IDSS). The tool's key function is to support the interactive development of flood-risk-related strategies and one-dimensional hydrodynamic flood simulations. Additionally, it includes modules for ecological and spatial analysis, multi-criteria evaluation, flood-risk maps, flood frequency, flood duration, and communication. In a case study of Hamburg and Lower Saxony, Germany, Evers and Krause (2007) proposed an integrated catchment-based development planning approach that emphasises the value of the IDSS tools. The investigators claimed that these tools are already implemented at relevant agencies.

In Ireland, there is an attempt to share technologies that support spatial planning and flood-risk management. O'Donnell and Birnbaum (2005) carried out a Demonstration Programme under the Irish Spatial Data Infrastructure (ISDI) framework. This Demonstration Programme of ISDI delivered a Decision Support System to aid flood-risk management and emergency response in a Clonmel area case study in Ireland. The Programme identified some of the barriers to sharing GT in Ireland, including unclear data providers, diverse data formats, high costs, ownership constraints on data, confidentiality, low quality of metadata, and time demands.

However, these examples of infrastructures that share data for spatial planning and flood-risk management do not function to share models and systems. Moreover, the examples of sharing models and systems are not developed as infrastructures, despite the fact that an infrastructure is necessary because it applies standards that smooth the sharing and communication process (Monteiro & Hanseth, 1996). Boerboom (2013) suggested that, at present, there is no such spatial planning and decision-making infrastructure, although it is a promising direction to pursue.

4.2. SIPI

The examples in Section 4.1 call for the development of an infrastructure that shares both GI and GT for the integration of spatial planning with flood-risk management. This study names such an infrastructure the 'Spatially Integrated Policy Infrastructure (SIPI)'. SIPI is a constellation of Information Infrastructures (II) and Information Systems (IS) that relies on broad Information and Communication Technologies (ICT) (Fig. 2). Because SIPI is spatial, it is based on particular types of ICT: GI and GT. SIPI is developed as Spatial Data Infrastructure and integrated with spatial IS such as Geographic Information System (GIS), Planning Support System (PSS), and Decision Support System (DSS).

The fundamental SIPI concepts are defined in Table 4, but other definitions exist. The concepts are grouped into three layers based on their functions and levels of generalization. ICT is the most fundamental and general, whereas IS is the most specific; II rests in the middle. The concepts at a level equivalent to ICT are GI and GT. At the second level (II), there are the concepts of spatial data infrastructure (SDI) or geospatial information infrastructure (GII). SDIs are not fundamentally different from generic information infrastructures, but they specialize in handling spatial data with geographic principles and tools (De Man, 2007).

With the increasing sophistication of studies in this field of geographic II, new terminologies and a variety of viewpoints have emerged. Liang, Croitoru, and Tao (2005) considered the 'Geospatial Infrastructure' as one backbone component of Geo-Web. Stock et al. (2012) used the 'Geospatial Knowledge Infrastructure' to emphasise the importance of knowledge interoperability. In a study conducted by Heinen, Kiemle, Buckl, Mikusch, and Loyola (2009), the 'Geospatial Service Infrastructure' was used to highlight the service-oriented process in the geo-information interoperation. Yang, Raskin, Goodchild, and Gahegan (2010) used the term 'Geospatial Cyber-Infrastructure' to imply that a geographic information infrastructure is a product in this data-rich and information-driven world. The concepts at the level of IS are the Geographic Information System (GIS), the Planning Support System (PSS) and the Decision Support System (DSS). These systems are geographic technology-based instruments that aid exploration of specific problems and support professional planning and decision-making tasks (Pelzer et al., 2014).

The purpose of grouping these concepts into different layers was to provide a foundation for the conceptualization and definition of SIPI and its appropriate categorization in the right layer. The differences among these concepts have been discussed in other literature; for example, differences among PSS, GIS, and DSS (Geertman & Stillwell, 2004) and between IS and II (Star & Ruhleder, 1996) have been considered. However, the categorization of the concepts is by no means mutually exclusive and they tend to overlap. For example, GIS often forms part of PSS and DSS (Geertman & Stillwell, 2004). In addition, a concept may have a narrow definition and a broad definition, which create indistinct boundaries. For example, the narrow definition of GT concerns a variety of techniques, tools, and instruments, whereas its broader definition may include database technologies and geospatial services (Van Manen et al., 2009).

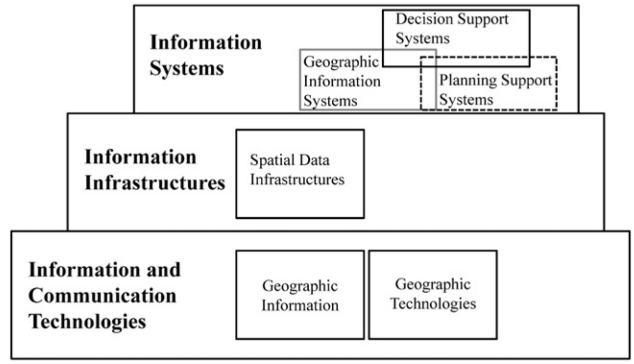

Fig. 2. Fundamental concepts underlying the definition and development of SIPI.

With respect to these relevant concepts in the context of geography, planning, and computer science, SIPI is defined as a complex infrastructure of data, knowledge, and services based on GI and GT. The SIPI applies tools, such as Geographical Information Systems (GIS), Decision Support Systems (DSS), Planning Support Systems (PSS), and tools for modelling, analysis, and visualization. Its objectives are to support the integration of spatial planning with flood-risk management and to bring stakeholders together through the Geo-Web on platforms such as desktop computers and laptops.

4.3. Conceptual framework of SIPI

We propose that a SIPI for an integrated spatial planning with flood-risk management should encompass three elements: (1) data and information, (2) decision support and scientific analysis tools, and (3) access tools and protocols. These three elements are targeted at distinct integration dimensions, and they interact with each other within the SIPI framework (Fig. 3). These elements address some of the integration issues mentioned in Section 3.2, particularly issues regarding information and technology. However, SIPI is not a universal solution to all of the issues relevant to integrating SP and FRM and efforts from disciplines outside of information and technology are critical to this integration.

4.3.1. Data and information

Sharing comprehensive information related to development and flooding, in the historical and current contexts, would benefit territorial integration. By collecting data from all the jurisdictions and creating a transparent information base, it would be quick and easy to assess the extent of consistency among neighbouring jurisdictions or between higher and lower jurisdictional levels. For example, SIPI makes it straightforward to examine whether a local plan contradicts a regional plan by overlaying the two plan maps.

4.3.2. Decision support and scientific analysis tools

The second element, sharing decision support and scientific analysis tools, focuses on predicting future scenarios to support policy integration, particularly the process of integrating policy. Tools, such as land-use models and hydrological models, are valuable for supporting policy integration because they can evaluate alternative policies with comprehensive consideration of flood mitigation objectives and development objectives. For example, sharing flood-risk assessment models with planners enables them to assess and consider the effects of optional forward plans on flood features. For another example, sharing planning support tools, such as land-use models, enables flood-risk managers to predict human impacts, such as development and land-use changes, on flood extent. Sharing the models mentioned here is not the same thing as sharing the output of the models; it is sharing the modelling process through access. This sharing cannot be successful without

Table 4
Definitions of fundamental concepts and their value to SIPI.

Term	Definition	Value for SIPI	Value for integrating SP and FRM
Information and communications technology (ICT)	ICT is the use of key applications, e.g., spreadsheets, databases, graphics, and web design software (Van Manen et al.(2009), p.1)	ICT is the foundation of SIPI	Provides foundation for digital sharing and communication
Geographic Information (GI)	GI is data based on geographic location (Goodchild (1992)). GI is collections of facts and other evidence about places on, above, and below the surface of the earth in traditional format of paper maps, globes, or atlases or as digital representations (Goodchild and Proctor (1997), p. 3)	Provides a data basis for SIPI	Sharing GI may lead to exchanges of opinions and values
Geographic Technology (GT)	GT includes geographic information systems and modelling (Van Manen et al. (2009), p. 1)	Provides technological basis for SIPI	Sharing GT supports sharing knowledge, expertise, and norms
Information Infrastructure (II)	II is a shared, open, unbounded, heterogeneous, and evolving socio-technical system consisting of a set of IT capabilities and their user, operations, and design communities (Hanseth and Lyytinen (2010), p. 4)	Provides theories and establishes rules, implementation, and evaluation methods for SIPI	II targets information-sharing, which is one step towards integration
Spatial Data Infrastructure (SDI)	SDI is to maximize the use of geographic information. SDI implementation involves a wide range of activities… not only technical matters such as data, technologies, standards, and delivery mechanisms, but also institutional matters related to organizational responsibilities, overall national information policies, and financial and human resources. (Masser (2005), p. 17)	Provides frameworks, methodology, and experience of spatial data exchange	SDI supports spatial information sharing that supports territorial integration
Information System (IS)	IS (or information technology system) is a complex organization of hardware, software, procedures, data, and people developed to address tasks faced by individuals and groups, typically in an organizational setting (March and Smith (1995), p. 252)	IS studies are fruitful to provide broad theories and experience for SIPI	IS provides general instruments and theories
Geography Information System (GIS)	GIS describes, explains, and predicts patterns and processes in geographic scales. GIS is a science, a technology, a discipline, and an applied problem-solving methodology (Longley, Goodchild, Maguireand Rhind (2005), p. xi)	Provides tools for SIPI and a system to apply geographic theory and principles	GIS merges data across disciplines and allows for the conduct of combined analyses
Decision Support Systems (DSS)	DSS is computer technology solutions that can be used to support complex decision making and problem solving. DSS is comprised of data base management capabilities, modelling functions, and user interface. (Shim et al. (2002), p. 111)	DSS is an important component of SIPI	Integrated DSS systems support integrated decision making and support policy integration
Planning Support Systems (PSS)	PSS is a subset of computer-based geo-information instruments that incorporates a unique suite of components that planners can utilize to explore and manage their particular activities (Geertman and Stillwell (2004), p. 291)	PPS is a crucial component for SIPI through which planning, theory, and principles can be applied	Integrating flood consideration in PSS plays a part in integrated spatial planning, particularly policy integration

standardised, open, friendly, and understandable models. Therefore, SIPI must include decision support and analysis tools for both spatial planning and flood-risk management so that an integrated policy-making process can be facilitated.

4.3.3. Access tools and protocols

The third element, access tools and protocols, supports instant communication that responds to and connects with stakeholders through geo-communication technologies. It plays a part in communication, cooperation, and coordination among institutions. Access tools and protocols are the bridges through which data and tools are shared. The development and maintenance of these bridges is the outcome of communication and cooperation among institutions. In turn, access tools and protocols promote institutional collaboration and transparency by sharing information, knowledge, and interests (Carey, Beilin, Boxshall, Burgman, & Flander, 2007). The lack of access tools and protocols can prohibit the building of consensus and partnership among institutions (Borisova, Racevskis, & Kipp, 2012).

The three SIPI elements should be interdependently designed because, as integration dimensions, they are interrelated. Data are both input and output of various models and analysis tools. The data and decision support tools are then shared through the access tools and protocols. The SIPI elements must work together as a unit so that SIPI can maximize its functions to integrate in all of the dimensions: territorial, policy, and institutional. The examples of existing spatial data infrastructures and platforms presented in Section 4.1 are limited to elements of information and access tools. The secondary elements of decision support and analysis tools are not shared through the infrastructures. Thus, it seems reasonable that the potentials of GI and GT for integration are limited.

5. Discussion and conclusion

This study highlights the necessity of integrating spatial planning with flood-risk management particularly in the Irish and the European context. By integrating these two fields, we are more likely to solve the problems of balancing development demands with flood mitigation objectives. To reach an improved understanding of this integration, this study reviewed the relevant literature and generalized three dimensions of integration: (1) territorial, (2) policy, and (3) institutional. Applying these three dimensions in the context of integrating spatial planning with flood-risk management, this paper identified the key issues in order to gain a better understanding of the difficulties inherent in the process of integrating spatial planning with flood-risk management.

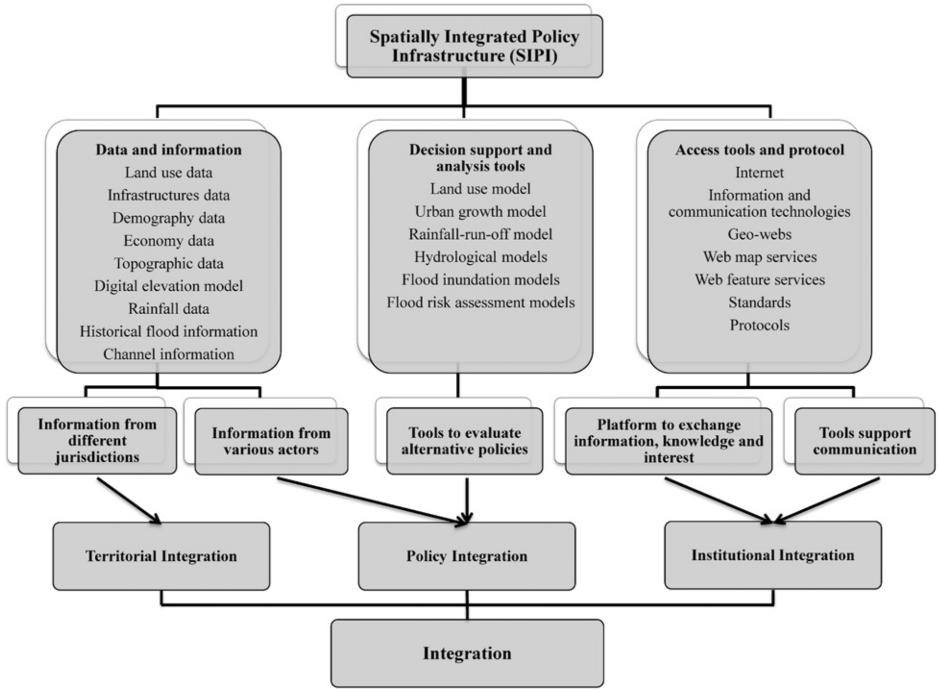

Fig. 3. The conceptual framework of SIPI.

In that context, the potential of GI and GT to support such integration was discussed. The potential value of these tools is recognized by existing projects and research on data and information sharing. However, the potential can be increased if an infrastructure is developed that also shares decision support and analysis tools for spatial planning and flood-risk management. Therefore, an infrastructure is called for, which we name Spatially Integrated Policy Infrastructure (SIPI), to achieve that goal of sharing data and decision support tools. This SIPI should encompass three elements: (1) data and information, (2) decision support and analysis tools, and (3) access tools and protocols.

This study is significant in identifying the connections between SIPI elements and integration dimensions: territorial, policy, and institutional. Sharing data and information play a part in territorial integration. Access tools and protocols are channels to communicate and build common interest among institutions. Particularly, the necessity of sharing decision support and analysis tools is highlighted in order to support rational policy screening and evaluation process and thus improve the level of policy integration. This framework helps a better understanding of potentials of geographic information and technologies in integration.

To develop SIPI and fulfil its role for integration, many barriers and difficulties need to be overcome. The technical difficulties of sharing models and analysis tools are challenges that directly relate to the development of SIPI. Sharing spatial data through information infrastructures is achievable because it was proven so by the development of existing Spatial Data Infrastructures.

However, sharing the decision support and analysis tools, such as planning and flood models, is still complex and difficult to achieve. One reason for this difficulty is that there are a great variety of inundation models with different algorithms, resolutions, and levels of precision, but no standard model to be widely used for specific spatial and temporal scales. Moreover, standardising the modelling methods for the purpose of planning and flood-risk management involves not only technical issues; it demands a complex of expertise, a heavy cognitive load, legislated policy, and existing modelling history and cultural. Intellectual property rights must be considered as well when selecting the models to be shared.

Despite its potential, SIPI's role in integration should not be exaggerated because its functional success is influenced by many other factors, such as the context of the institutional and political settings in which it is applied. Different institutions have different legal mandates and political drivers and, often, there are powerful interests that work on behalf of the status quo. For example, in the Netherlands, planning is largely disengaged from the flood defence infrastructure on the assumption that the defences will never fail. In this case, SIPI could be used, but it may not make much difference. However, in the UK, the context is quite different. There, insurers (responsible for paying out) and the Environment Agency (responsible for providing flood protection) are increasingly pressuring planners to stop developing in flood-prone areas. There are similar dynamics in the US, played out by its national flood insurance programme and by the US Army Corps of Engineers, which is increasingly keen on non-structural flood-risk management measures for handling its huge backlog of projects. In these countries, a desire for integration may be stronger, which could promote the use and functional success of SIPI.

This study proposes not only a conceptual framework of SIPI but also a framework for further studies on the development and evaluation of GI and GT in integration of spatial planning with flood-risk management. Technical studies should be carried out on prototyping SIPI, particularly on sharing decision support and analysis tools through, for example, web process services. Integration dimensions recognised in this study need to be developed into measurements. Particularly, studies on measuring policy integration dimension are necessary in order to evaluate the functionality of SIPI. The potential role of SIPI in each integration dimension is identified in this paper, but it needs to be tested and proved in further empirical studies.

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