1 Introduction

The Directorate-General for Mobility and Transport of the European Commission reported an ongoing increase in the transport load of goods and passengers in Europe [1, p. 21]. This goes hand in hand with increased demands on European transport infrastructure, including bridges. Analyses from Germany show that numerous bridges require maintenance and repair as well as strengthening because of the grown bearing load. Germany's country administration counts nearly 40 000 bridges, approximately 12% of which are rated as insufficient [2, p. 8 and 9]. Moreover, each state within Germany manages additional bridges that are not considered by the national report. In summary, the demands on bridges are growing and numerous bridges require either maintenance and repair or have to be replaced.

80% of the German Bridges mentioned above shall be replaced [2, p. 19] without providing information about the reasons for these decisions. It is striking that strategic, economic and technical aspects are considered, but environmental aspects, e.g. the emission of CO_2, are apparently not [2, p. 22]. On the one hand, it is conceivable that replacement is cheaper compared to repair because of lower staff efforts; thus, replacement is preferred. On the other hand, the current climate crisis requires us to lower the emission of greenhouse gases, including CO_2. Under the consideration that currently the cement industry is responsible for 5% of the global CO_2 emission [3], it would stand to reason that we should lower our demand of cement, i.e. of concrete. Accordingly, repair and maintenance of bridges should be preferred over replacement. In order to make these conflicting objectives, costs and CO_2 emissions, more compatible, two approaches are possible. The first would be to include the economic effects of greenhouse emission into the calculations for repair [4]. Secondly, lowering costs for repair and maintenance in order to make maintenance and repair more attractive to stake holders. This dissertation focuses on the task to lower the costs for maintenance and repair by improving the digital data acquisition thereby laying the foundation for automatic processing of bridge condition data.

To ensure traffic and structural safety as well as durability, bridges are inspected frequently. Registering condition states, performing assessments, and preparing data for inspection and maintenance tasks are time consuming and error prone because of highly paper based workflows and manual copy pasting. An improvement in digitizing bridge condition data decreases the demand of manual work, help to lower financial efforts for these tasks; therefore, make maintenance and repair more attractive. In the long term, this would lower costs and make repair and maintenance more attractive.

Figure 1.1 shows an overview of several tasks for bridge inspection and maintenance. This starts with the bridge inspection (1), at which an inspector or engineer visits the bridge and notes all defects observed. Most of the defects are easy to spot; whereas others are may be identified by tapping with a tapping hammer. Later on, the collected defect data is used to directly assess the bridge condition. In case of uncertain failure modes or suspected defects under the surface, additional data acquisition, such as Non-Destructive Testing (NDT) or Structural Health Monitoring (SHM) may be considered. All retrieved data has to be analyzed in order to define the bridge rating (2). According to national standards, the severity and extent of the defects are rated based on defect parameters. Further analyses may be done by structural engineers. Next, bridge condition prediction may be done (3), like condition predictions of components or the entire bridge, simulation on damage propagation, or reliability simulations. Before maintenance actions can be executed (5), they need to be planned (4), which includes process, resource, and cost planning. All steps are related to bridge condition data from the structure gained by inspections, analyses, and simulations. Hence, this data needs to be exchanged in a suitable and structured way with semantic and geometric information. To address these requirements, a data model is required that includes both damage and building information. This results in the need for Damage Information Modeling (DIM). Damage Information Modeling (DIM) means to integrate geometric and semantic damage and building information. Resulting models of damaged bridges are called DIM models or as-damaged Building Information Modeling (BIM) models.

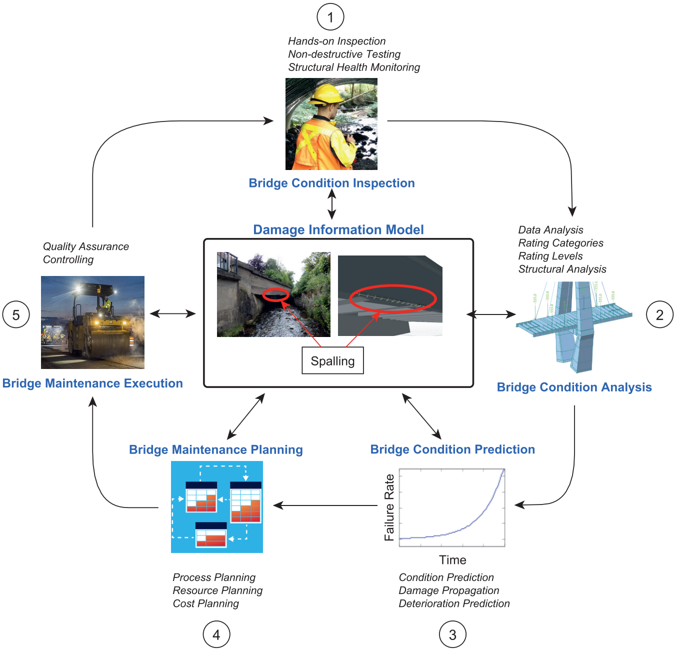

Figure 1.1: Process cycle and data exchange for bridges' assessment and maintenance. Photos and images that are part of this figure are from the "Thüringer Landesamt für Bau und Verkehr" as well as from the following references: [5]–[9]

As shown by Borrmann, König, Koch, *et al.*, the information loss and time effort for information exchange during building design, planning, and construction phase may be reduced by automating information exchange using BIM [10]. The digital model includes semantic and geometric information required for subsequent processes. All data is saved in a digital format and sent to the targeted stakeholder. The same advantages are offered by DIM for the operating phase: data exchange is automated and accelerated.

Besides the simplified data exchange, a further advantage of digital models is that they can be processed automatically. For example, automatic clash detection helps to prevent construction errors, or automatic energy analyses help to reduce energy consumption [10]. Similar to that, DIM could offer new automated workflows in the operating phase, such as structural analyses, deterioration simulations, and maintenance planning.