1. **Models for Noise Control and Sound Design**
   1. **Impact Sound Insulation**

The vibration transmissions (impact sound) in built-up structures is very important for human comfort, health and safety and causing steadily growing annoyance due to the impact noises in dwellings. Most of the work available on the impact sound insulation prediction is done in multifamily apartments where people are annoyed by those noises which are mainly caused by structure borne sounds. In the residential and worksite premises, especially in the urban areas, the international standards provided by international standardization organization (ISO) have reflected the trends in growing annoyance due to the indoor as well as outdoor noise. However, there are certain aspects of noise to be taken into account to provide an optimal acoustic satisfaction and an accurate evaluation of building performances. In the previous section the prediction and auralization of airborne sound insulation was the focus point, where we discussed the sound transmission through a system of partition walls (adjacent rooms as well as façades) caused by airborne source such as conversation, TV or radio sounds, and outdoor traffic noise. In this section, we now move straightforward toward the general discussion of sound transmission through building structure caused by vibrations of these structures, which is related to the excitation of solid structures by forces. The source, therefore, is to be characterized by its force output or by its velocity injected into the medium [**REF-RTH**]. With the velocity in the structure known, transmission and radiation of sound to a receiver can be considered a solution of the problem. The basic definitions and methods for predicting and evaluating impact sounds are given in next sections where we will discuss available prediction model defined by ISO and find the suitable techniques to develop an auralization models from these standards.

* + 1. **Impact Sound Insulation Model**

Compared with that described for airborne sound insulation, modelling and auralization of impact sound generated by walking or jumping on a floor is more difficult [**REF-MVO**]. The details of impact sound can be found in Chapter **X**, however, the main focus will be to discuss the impact sound insulation auralization, which should include quantities as the force-time signal of the impact source, the impedance of source and floor, the radiation efficiency of the building elements under impact force and the characteristics of the receiving room. A possible detailed model is given in Figure **14.1**, which requires normalized impact sound pressure and the structure borne reverberation time as input data. We base on an algorithm for auralization on these commonly available quantities. At first we need an ideal force source with an inner impedance acting upon floor impedance and transform it into a real force as shown in Figure **14.2**. It should be noted that all data of the Impact sound model and impact noise levels of floors are defined on the basis of the tapping machine. Therefore, a source (i.e. a tapping machine, walker) is considered as an ideal force source acting upon an impedance (a two-port ) which is given by the mechanical impedance of a leg and shoe of a walker or the impedance of one hammer of a tapping machine. These elements can be transformed into a real force source with a force and an inner impedance . This real force source is connected to a two-port with the input quantities and as shown in Figure **14.3**. The quantities at the output are the sound pressure and particle velocity in the receiving room. For measurements of heavy weight concrete floor with a standard tapping machine the inner impedance of the source can be neglected since it is much smaller than the input impedance of the two-port which is formed by the floor impedance. Thus, this model can be taken as a description of the measurement of the impact sound pressure level .

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| **Figure 14.1:** Auralization model of impact sound insulation [**REF-RTH**] |

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| **Figure 14.2:** Ideal force source Model [**REF-RTH**] |

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| **Figure 14.3:** Model for real force source connected to a two-port, representing concrete floor and receiving room [**REF-RTH**] |

It can be said that quantities describing the excitation of the floor by the source, the radiation in the receiving room, and the receiving room characteristics are already contained in the two-port and thus in impact sound pressure level for the given configuration in the measurement. The task is to remove the influence of the source (i.e. tapping machine) and the receiving room on the quantity and replace it by the desired force source and receiving room.

The principle for auralization of impact sound insulation is basically same as for auralization of airborne sound insulation except for the excitation mechanism in the source room. The sound pressure in the receiving room can be obtained by **1)** dividing the normalised impact sound level by the force spectrum of the tapping machine, **2)** multiplying the result with the complex force spectrum of the chosen force source and **3)** modelling the sound field in the receiving room (i.e. reverberation). The receiver room acoustical model is described in airborne sound isolation auralization section. Another important point is the feedback between the source and the building structure in the source room, whereas, for the airborne sound transmission this feedback between source and the load (which is the radiation impedance) was neglected because of the impedance relation and for impact sound excitation the impedance relation may be smaller especially for excitation of light-weight structures by tapping machines. The previous studies show that the measurements of light-weight and heavy-weight floors with a tapping machine are not comparable [**REF**]. Therefore, it is necessary to measure impedance of the sources and floors for the auralization. The measurement setup and the procedures for forces and impedances can be found in [**REF-RTH**]. Furthermore, nonlinearities have to be taken into account in case of timber floor constructions excited by low frequency heavy impacts. The estimation presented in this model is again following the approach of SEA, such as in airborne sound insulation. The modal (resonant) response is the basis of statistical energy flow between the subsystems of floors, walls and rooms. The frequency range is thus limited to the range above critical frequencies, where the energy balance in various building and laboratory situations is a good estimate of the impact sound level. Specific singular modal effects, forced transmission and nonlinearities are neglected. The total vibration and radiation into the receiving room is obtained by adding the energy for all transmission paths. The basic relationship for impact sound level is given in Equation 14.1.

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|  | **(14.1)** |

Such as in airborne sound transmission, the model parameters are to be corrected with regard to the losses in the actual field situation (represented by the structural reverberation times ) and denoting the reference laboratory conditions.

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|  | **(14.2)** |

Additional layers such as suspended ceilings or wall linings are accounted for by subtracting the airborne or impact sound improvement, or , from the impact sound level given in Equation **14.3**.

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|  | **(14.3)** |

Similarly, for the flanking paths

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|  | **(14.4)** |

Equation **14.4** includes influences of junction level differences in the actual field situation. Furthermore, the impact sound reduction of linings, floating floors and suspended ceilings cannot be transferred easily from one bare floor system to the next, particularly when comparing massive and timber bare floor constructions. In case of unknown floor construction or when just a rough estimate of the floor construction is required, the normalised impact sound pressure level of a monolithic massive floor can be calculated from the mass per unit area the losses expressed by the structural reverberation time the radiation efficiency and the frequency (in Hertz). The final impact sound level then is given in Equation **14.5**.

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|  | **(14.4)** |

* + 1. **Impact Sound Insulation Auralization**

A simple model for a simple auralization without considering the dynamic interaction between source and floor is discussed in this section. A model for the sound pressure level in the receiving room from a tapping machine (TM) in the source room can be taken from [**REF-GER**], which is given as,

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|  | **(14.5)** |

With denoting the sound pressure in the receiving room caused by a tapping machine, the radiation efficiency, as the mass, as the area, as the force injected by the tapping machine, and and as the reverberation time and impedance of the structure (i.e. floor) respectively. We can see that the relation between sound pressure and force are determined by a term which is only dependent on the floor construction. Assuming a linear behaviour the sound pressure resulting from a different force source () can be obtained by the expression given in Equation **14.6**.

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|  | **(14.6)** |

With and denoting sound pressure and force caused by an arbitrary force source. We can find an expression for the sound pressure in the receiving room depending on the normalised impact sound level from different transmission paths and the reverberation time considering Equation 14.6, which yields the following expression. Where all are the normalised impact sound levels of the independent paths and is the reference sound pressure.

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|  | **(14.7)** |

The quantities that are used as input data for the auralization are the normalised impact sound pressure levels for each transmission path, the force of the tapping machine and the desired force source to be auralized , and the receiving room reverberation time . The impact sound pressure levels are obtained by simulation software whereas the input forces are obtained from the measurements. As an example, the one-third octave spectra of the measured forces for a tapping machine, a modified tapping machine, and a rubber ball are shown according to ISO 140-11 [**REF**]. The spectra of the tapping machine and the modified tapping machine are similar at low frequencies, however, above 125Hz the force of modified tapping machine gets significantly smaller because of its rubber layer between hammer and floor. Here, it should be noted that due to properties of the measurement setup the measured force of the tapping machine seems to be too low above . To use in the auralization of common sources this is not a big problem as this frequency range can be neglected.

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| **Figure 14.4:** Ground reaction forces for a tapping machine, a modified tapping machine and a rubber ball in one-third octave bands [**REF**] |

In order to auralize the impact sound a force-time signal of the suitable length is constructed from several measured force pulses of the source. For example, from two or three force pulses of one hammer of a tapping machine a force-time signal can be constructed by appending the pulses at an interval of seconds. Jittering might be introduced in time and amplitude of force-time signal to produce the sound more natural.