challenge is that the concepts related to validation are still being debated, and conflicts remain in the way that validation terminologies are used (Carley 1996; Crooks et al. 2007; Troitzsch 2004). Moreover, the different techniques for validation are quite varied, which has led to a confusing situation for modellers. Therefore, it is important to have a systematic approach to the overall validation process, and one that is integrated throughout the development phase of an agent-based model (ABM). This chapter attempts to provide such an approach to ABM validation.

Numerous publications have been devoted to reviewing different validation methods for ABMs (Berger et al. 2001; Carley 1996; Klügl 2008; Parker et al. 2002; Troitzsch 2004; Windrum et al. 2007). Among these, several types of validation are mentioned, e.g. empirical validation, statistical validation, conceptual validation, internal validation, operational validation, external validation, structural validation and process validation. However, Zeigler (1976) provides a good characterization of these methods into three main types:

- **Replicative validation:** where model outputs are compared to data acquired from the real world;
- **Predictive validation:** where the model is able to predict behaviour that it has not seen before, e.g. that which might come from theories or which might occur in the future; and
- **Structural validation:** where the model not only reproduces the observed system behaviour, but truly reflects the way in which the real system operates to produce this behaviour.

In this chapter, the focus is on structural validation, which in broad terms consists of the following four processes as defined below (Carley 1996; Klügl 2008):

- **Face Validation:** is often applied at the early phase of a simulation study under the umbrella of conceptual validation. This technique consists of at least three methodological elements:
  - **Animation assessment:** involves observations of the animation of the overall simulated system or individual agents and follows their particular behaviours.
  - **Immersive assessment:** monitors the dynamics of a particular agent during the model run.
  - **Output assessment:** establishes that the outputs fall within an acceptable range of real values and that the trends are consistent across the different simulations.
- **Sensitivity Analysis:** assesses the effect of the different parameters and their values on particular behaviours or overall model outputs.
- **Calibration:** is the process of identifying the range of values for the parameters and tuning the model to fit real data. This is conducted by treating the overall model as a black box and using efficient optimisation methods for finding the optimal parameter settings.
- **Output Validation:** involves graphically and statistically matching the model's

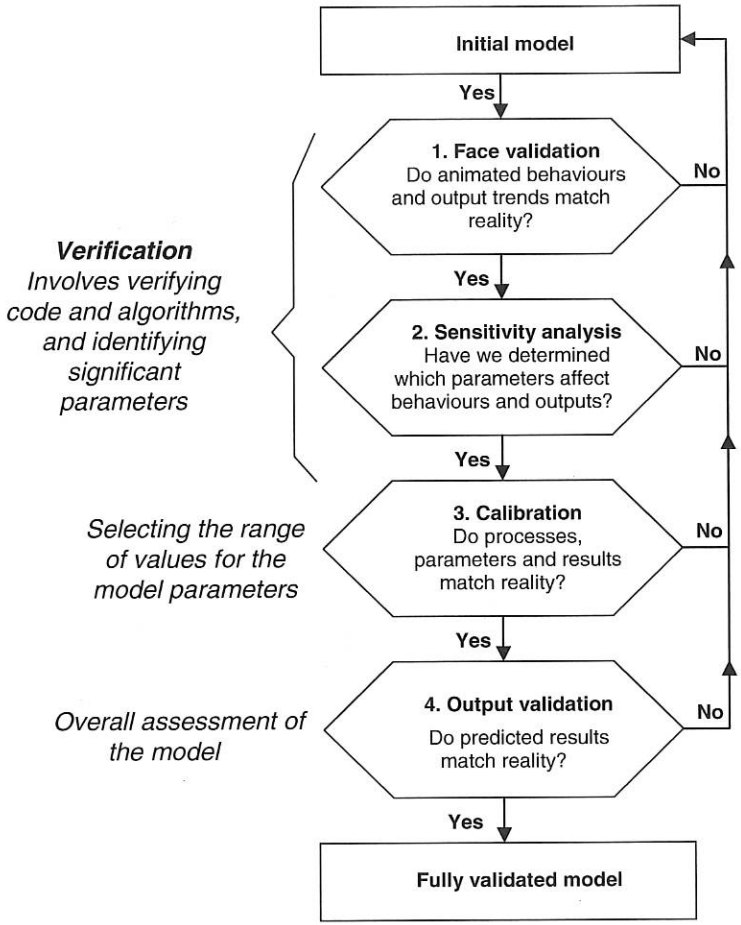

Fig. 10.1 General validation process of an ABM

Face validation and sensitivity analysis are sometimes collectively referred to as verification (Parker et al. 2002). The different processes above are often carried out iteratively in a step-by-step process as illustrated in Fig. 10.1.

A model is able to generate reliable and valid results within its experimental frame only if these validation processes are wholly implemented. However, there are very few examples of where comprehensive system validation has been applied to ABMs. For land use and land cover change modeling in particular, many studies have only concentrated on *output validation* (e.g. Castella and Verburg 2007; Jepsen et al. 2006; Le 2005; Wada et al. 2007) whereas the other steps mentioned above have not been treated explicitly. Therefore, the results may not truly reflect the way the system operates as per the definition of struc-